This document is guaranteed to be current only to issue date.

Some Mars Global Surveyor documents that relate to flight operations are under revision to accommodate the recently modified mission plan.

Documents that describe the attributes of the MGS spacecraft are generally up-to-date.

542-300

Mars Global Surveyor

Investigation Description and Science Requirements Document

February 1995

Jet Propulsion Laboratory
California Institute of Technology

JPL D-12487

542-300

Mars Global Surveyor

Investigation Description and Science Requirements Document

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JPL D-12487

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ACRONYM LIST

AACS	Attitude and Articulation Control Subsystem
AEM	Autonomous Eclipse Management
APL	Applied Physics Laboratory
ARIA	Airborne Range Instrumentation Aircraft
ASU	Arizona State University
AU	Astronomical Unit (149,597,870 km)
BCE	Bench Checkout Equipment
BER	Bit Error Rate
BIU	Bus Interface Unit
bps	Bits Per Second
C_3	injection energy per unit mass
CCAFS	Cape Canaveral Air Force Station
C/CAM	Collision and Contamination Avoidance Maneuver
C&DH	Command and Data Handling
CCD	Charge-Coupled Device
CDS	Command Data Subsystem
CDU	Command Detector Unit
CIU	Controls Interface Unit
CNES	Centre National d'Études Spatiales
CPU	Central Processing Unit
CR	Mission Change Request
CSA	Celestial Sensor Assembly
CT	Cross Track
DLA	Declination of Launch Asymptote
DOD	Depth Of Discharge
DSCC	Deep Space Communications Complex
DSN	Deep Space Network
DSS	Deep Space Station
ECR	Engineering Change Request
EDF	Engineering Data Formatter
EDR	Engineering Data Record
EDT	Eastern Daylight Time
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference

ENG	Engineering
EOM	End Of Mission
	Engineering-Only Mode (data mode)
ER	Electron Reflectometer
ESMC	Eastern Space and Missile Center
ET	Ephemeris Time
ETE	Earth True Equator (and equinox) of Epoch
eV	Electron Volt
FOV	Field of View
GCO	Gravity Calibration Orbit
GDS	Ground Data System
GFP	Government Furnished Property
GRS	Gamma Ray Spectrometer
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HEF	High Efficiency
HGA	High-gain Antenna
HRC	High-rate Record (data mode)
I	Injection
ICD	Interface Control Document
IDS	Interdisciplinary Scientist
IDSRD	Investigation Description and Science Requirements Document
IFOV	Instantaneous Field of View
IMU	Inertial Measurement Unit
IOPG	Instrument Operations and Planning Group
ITL	Integrate-Transfer-Launch facility
JHU	Johns Hopkins University
JPL	Jet Propulsion Laboratory
kbps	Kilobits per Second
KSC	Kennedy Space Center
ksps	Kilosymbols per Second
L	Launch
LGA	Low-gain Antenna
LRC	Low-rate Record (data mode)
LSB	Least Significant Bit
MAG	Magnetometer

MAG/ER	Magnetometer/Electron Reflectometer
MC	Mapping Cycle
MFLOPS	Million Floating-Point Operations Per Second
MGS	Mars Global Surveyor
MHSA	Mars Horizon Sensor Assembly
MIL-71	Merritt Island DSS #71
MIPS	Million Instructions Per Second
MO	Mars Observer
MOC	Mars Orbiter Camera
MOI	Mars Orbit Insertion
MOLA	Mars Orbiter Laser Altimeter
MOS	Mission Operations System
MOT	Mars Orbiter Transponder
MR	Mars Relay
MRC	Medium-rate Record (data mode)
MRD	Mission Requirements Document
MS	Mapping Sequence
MSB	Most Significant Bit
MSSS	Malin Space Science Systems
NA	Narrow-Angle (also N/A)
NASA	National Aeronautics and Space Administration
OCM	Orbit Change Maneuver
ORT	Operational Readiness Test
OTM	Orbit Trim Maneuver
PB	Playback (also P/B)
PDB	Project Database
PDS	Payload Data Subsystem
	Planetary Data System
PHSF	Payload Hazardous Servicing Facility
P_i	Probability of Impact
PI	Principal Investigator
PLF	Payload Fairing
PROM	Programmable Read-Only Memory
PSA	Partial Shunt Assembly
PSG	Project Science Group
PST	Pacific Standard Time

RAM	Random Access Memory
RF	Radio Frequency
ROM	Read-Only Memory
RPA	Radio frequency Power Amplifier
rpm	Revolutions Per Minute
rms	Route Mean Square
RS	Radio Science
RT	real-time (also R/T)
RTC	real-time Commands
RTH	Real-Time/High-rate record (data mode)
RTL	Real-Time/Low-rate record (data mode)
RTM	Real-Time/Medium-rate record (data mode)
RWA	Reaction Wheel Assembly
S/C	Spacecraft
S&E	Science and Engineering
SCP	Standard Control Processor
SEM	Sun-Earth-Mars angle
SEU/SEL	Single Event Upset/Single Event Latch-up
SIRD	Support Instrumentation Requirements Document
SME	Sun-Mars-Earth angle
SNR	Signal-to-Noise Ratio (also S/N)
SOPC	Science Operations and Planning Computer
sps	Symbols Per Second
SRM	Solid Rocket Motor
STL	Spacecraft Test Lab
SW	Software (also S/W)
TBD	To Be Determined
TBR	To Be Revised
TBS	To Be Supplied
TCM	Trajectory Correction Maneuver
TES	Thermal Emission Spectrometer
TMO	Transfer to Mapping Orbit maneuver
UHF	Ultra High Frequency
USAF	United States Air Force
USGS	United States Geological Survey
USO	Ultra-Stable Oscillator

UTC	Universal Time - Coordinated
VLBI	Very-Long-Baseline Interferometry
WA	wide-angle (also W/A)
XSU	Cross-Strap Unit

1. INTRODUCTION

1.1 PURPOSE

The Investigation Description and Science Requirements Document (IDSRD) is the controlling documentation for all science requirements placed upon elements of the Project concerned with the development of the Mars Global Surveyor (MGS) spacecraft and its mission. Early delivery of this document serves to ensure that designs by these elements are consistent with the achievement of science goals, as well as to provide a vehicle for the negotiations and to obtain a clear understanding of those requirements which the Project commits to implement within the overall resource constraints.

As many of the former Mars Observer (MO) Mission objectives and experiments constituted the MGS science compliment, this document has been carried forward with change bars and “deleted” as indicators of the differences from the previous MO Project Document.

Distribution of the changes to the IDSRD shall be controlled by the Project. All requests for additions, changes or deletions to the IDSRD shall be submitted to the Science Manager and coordinated according to the Project's Configuration Management Plan.

1.2 REQUIREMENT CATEGORIES

"Requirement" as used in this document refers to essential requirements that are basic to the proposed experiment science objectives and are accepted for implementation by the Project office. Requirements are listed in Section 2 and **bold**ed in Sections 3 through 7.

"Goal" or "desire" refers to a level of performance that exceeds the current understanding of project capabilities. Such requests, as the result of further study, may not be satisfied. Conversely, the Project may at a future date either add resources to permit achieving this goal or determine that the capability will occur but only during ideal periods of spacecraft/mission operations.

1.3 PROJECT ACTION

A Project review of these requirements has been conducted to identify all requirements which cannot be met or which require more analysis to ascertain their implementation feasibility (goals). Proposed changes to this document will be reviewed by Project Office personnel with consultation by appropriate JPL/Contractor representatives. Requests should be submitted through an experiment's Instrument Engineer or Experiment Representative.

1.4 DOCUMENT OVERVIEW

Section 2 provides a summary list of all Project accepted requirements in the order of reference as the appear in the following sections. Appendices A through D give the mission descriptive background necessary to place these requirements in context as follows: Appendix A: Mission Objectives; Appendix B: Mission Design; Appendix C: Spacecraft Description; Appendix D: Instruments Description and Measurements.

1.5 SCIENCE INVESTIGATIONS

The scientific objectives of the Mars Global Surveyor (MGS) Mission will be achieved with a complement of five instrument experiments and six interdisciplinary science investigations that have been selected by NASA's Office of Space Science. These investigations and their principal investigators (PIs, TLs or IDS), together with their JPL support personnel, are listed in Table 1-1.

Table 1-1. Mars Global Surveyor Investigations, PIs and Experiment Representatives

Investigation	Institution	Principal Investigator	Experiment Representative
Magnetometer (MAG)	Goddard Space Flight Center (GSFC)	Mario H. Acuña (301) 888-7258	Daniel Winterhalter (818) 354-3238
Mars Orbiter Camera (MOC)	Malin Space Science Systems (MSSS)	Michael C. Malin (619) 552-2650 ext. 500	Richard J. Springer (818) 393-7825
Mars Orbiter Laser Altimeter (MOLA)	Goddard Space Flight Center (GSFC)	David E. Smith (301) 286-8671	Bruce W. Banerdt (818) 354-5413
Radio Science (RS)	Stanford University	G. Leonard Tyler (Team Leader) (415) 723-3535	Michael J. Connally (818) 393-1072
Thermal Emission Spectrometer (TES)	Arizona State University	Philip R. Christensen (602) 965-7105	John L. Callas (818) 354-9088
Interdisciplinary Scientists (IDS)	Washington University	Ray Arvidson (314) 889-5609	Richard J. Springer (818) 393-7825
	U. S. Geological Survey - Menlo Park	Michael H. Carr (415) 329-5174	
	California Institute of Technology	Andrew P. Ingersoll (818) 395-6167	
	University of Colorado	Bruce M. Jakosky (303) 492-8004	
	U. S. Geological Survey - Flagstaff	Laurence A. Soderblom (602) 527-7262	
	Ames Research Center	Robert M. Haberle (415) 604-5491	

2. REQUIREMENTS SUMMARY

Listed below are the Project accepted science requirements which may be found highlighted in the following Sections 3, 4, 5 and 7.

SECTION	REQUIREMENT	SOURCE
3.2.2.1	Acquisition of data during the initial drift orbit is a requirement.	MAG1
3.2.2.1	An orbit with a period of approximately one day shall be maintained for a period of at least 28 days.	MAG2
3.2.2.2	The difference between the spacecraft orbital semimajor axis and the equatorial radius of Mars is required to be 350 ±50 km.	MAG3
3.2.2.3	It is required that the ground track separation between successive repeat period orbits be from l/3 to 1/20 of the orbit altitude.	MAG4
3.2.2.3	The ground repeat period must not be a small multiple (i.e., commensurable) of the solar rotation period as seen from Mars (26.354 Earth days).	MAG5
3.2.2.4	The minimum required number of mapping cycles is 10.	MAG6
3.2.2.5	It is required that the average mapping orbit be fixed in local time.	MAG7
3.2.3.1	It is required that the altitude of the spacecraft above the true surface of Mars be kept under 540 km.	MOC1
3.2.4.1	Deleted	
3.2.5.1	It is required that the MGS orbit should be near polar (inclination = 90° ±3°, 3σ).	MOLA1
3.2.5.1	The orbit shall be near circular with altitude variation not to exceed 105 km (peak to peak) and an average altitude above the Mars ellipsoid not to exceed 390 km.	MOLA2
3.2.6.1	It is required that the orbital periapsis altitude be between 250 km and 400 km.	RS1

3.2.6.2	The Radio Science Team requires a gravity calibration orbit (GCO) immediately preceding initiation of the mapping phase, essentially the same as the mapping orbit but with a repeat cycle of 7 to 10 days.	RS2
3.2.6.2	The spacecraft shall be tracked continuously (24 hours per day) over at least one full repeat cycle of the GCO.	RS3
3.2.7.1	It is required that the altitude of the spacecraft be maintained between 250 km and 2000 km.	TES1
3.2.7.2	It is required that each mapping cycle (56 days) be offset by more than 9 km in a consistent direction to permit the TES to observe the entire planet.	TES2
3.2.8.1	A near-polar Sun-synchronous, low-altitude orbit is required.	IDS1
3.2.8.1	The mapping cycle should be as brief as possible.	IDS2
3.2.8.4	The orbit required for this investigation is near-circular, Sun-synchronous, with a dayside equator crossing near 2 p.m. mean local solar time and with an orbital altitude between 330 km and 450 km.	IDS3
3.3.1	Deleted	
3.3.3.2	The MOC also requires accurate orbit position and timing reconstruction.	MOC2
3.3.4	Deleted	
3.3.6.1	Mapping orbit ephemeris predictions shall be provided by the MOS to the DSN 5 days in advance of the events.	RS4
3.3.6.1	These predictions shall include the times (at both immersion and emersion) when the propagation path from the spacecraft to Earth grazes the surface of Mars as well as the times when the propagation path is 200 km above the surface.	RS5
3.3.7	During the mapping phase, surface and atmospheric observations require a pointing control of 10 mrad and knowledge of 3 mrad about all axes.	TES3
3.3.7	Prediction of the equator crossing time will be required within 25 km along-track for the initiation of orbit sequence starts.	TES4
3.3.7	Crosstrack prediction of the spacecraft ephemeris will be required to within 10 km for planning of mosaic observations (99%).	TES5

3.3.7	The radial prediction requirement is 25 km.	TES6
3.3.7	After-the-fact reconstruction of the orbit ephemeris is required to within 9 km downtrack and 5 km cross-track for surface feature identification. The radial requirement is 10 km (except when Ipos = 90°).	TES7
3.4.1	Deleted	
3.4.2	Deleted	
3.4.2	It is required that the spacecraft remain in the drift orbit for at least 4 weeks prior to final mapping orbit insertion and that data be acquired continuously during this period (except during maneuvers).	MAG9
3.4.2	The minimum requirement is for data collection by the ER during a portion of the cruise and drift phase orbits.	MAG10
3.4.3.1	MOC requires that all maneuvers be announced sufficiently in advance to permit planning around their occurrence.	MOC3
4.1.1.1	Deleted	
4.1.1.2	Deleted	
4.1.1.3	Deleted	
4.1.2	The two triaxial fluxgate sensor assemblies shall be mounted such that the spacecraft stray field contribution to less than 3 nT with a maximum variability (DC to 10 Hz) of no more than +0.3 nT peak to peak.	MAG11
4.1.2	Deleted	
4.1.2	The ER detector location should avoid areas of motor exhaust plumes.	MAG13
4.1.2	It is necessary that the cabling from the electronics to the sensors be provided by the spacecraft contractor per the S/C MAG-ICD.	MAG14
4.1.2.2	ER detector FOV must include nadir.	MAG15
4.1.2.2	ER detector FOV should avoid spacecraft surfaces.	MAG16
4.1.2.2	ER detector FOV should minimize distortion of electron trajectories.	MAG17

4.1.2.2	ER detector FOV should be near the nominal direction of the interplanetary magnetic field, 122° (solar ecliptic coordinates) from the sunward line in the ecliptic plane.	MAG18
4.1.2.2	ER detector FOV should be known to 25 mrad.	MAG19
4.1.3.3	The MOC requires two unobstructed nadir views from the spacecraft to the surface of Mars. All fields of view are centered on the nadir axis (+Z).	MOC4
4.1.3.3	The wide-angle assembly has a 140° FOV in the cross-track (+Y) direction and must have an unobstructed FOV.	MOC5
4.1.4.1	Deleted	
4.1.4.3	Deleted	
4.1.5	The MOLA optical axis shall be positioned such that it is aligned with the +Z axis with an unobstructed field of view.	MOLA3
4.1.7.1	The TES instrument must be located on the spacecraft to have an unobstructed view in the orbital plane from nadir to space in a minimum of one direction.	TES8
4.2.1.3	Deleted	
4.2.1.4	Deleted	
4.2.2.4	Sufficient damping should be incorporated in the design to eliminate mechanical resonances, particularly in the torsional mode.	MAG20
4.2.2.5	Exposure of the ER to organic contaminants, either in vacuum tests or during the mission shall be avoided.	MAG21
4.2.3.2	When not operating, the MOC will require survival heater power.	MOC6
4.2.6	Once the USO is turned on, it shall not be turned off, because it takes 3 months to stabilize.	RS6
4.2.6.10	The spacecraft shall be capable of transmitting with the downlink carrier derived from the USO without regard to the lock status of the uplink receiver. The mode shall be selectable by configuration command and shall remain in effect until a reset command is executed.	RS7

4.2.6.10	The spacecraft shall be capable of removing telemetry from the downlink carrier. The resultant RF output from the spacecraft shall have no data subcarrier or sidebands present.	RS8
4.2.6.10	It shall be possible to configure the spacecraft so that the ranging channel and VLBI modulation are off. In this event, the spacecraft downlink shall have no ranging sidebands present.	RS7
4.3.1.1	Deleted	
4.3.2.1	The alignment between the sensors and the spacecraft reference axes should be known within 25 mrad.	MAG22
4.3.2.2	The spacecraft shall be capable of executing two-axis calibration maneuvers in the selected orbit without loss of control of MAG data acquisition capabilities.	MAG23
4.3.3.1	The MOC must point to the nadir within at least 10 mrad in pitch, roll, and yaw.	MOC7
4.3.3.1	Engineering telemetry must provide "after-the-fact" pointing information within at least 3 mrad in pitch, roll, and yaw.	MOC8
4.3.3.3	The MOC requires a reference timing pulse every 0.125 s, consistent to better than 0.0125 s.	MOC9
4.3.4.1	Deleted	
4.3.5	The spacecraft shall control the altimeter reference axis to within 10 mrad in each axis, and shall provide sufficient engineering measurements and telemetry to obtain attitude knowledge to within 3 mrad in each axis.	MOLA4
4.3.6.2	The unmodeled contributions of the received power of the downlink carrier shall not vary by more than 0.1 dB over any 50 second interval due to any spacecraft effects.	RS10
4.3.6.3	Deleted	
4.3.7.1	Spacecraft stability requirements are for a minimum of 1.0 mrad/s about the X and Y axes and 2.0 mrad about the Z axis.	TES9
5.1.1.1	Deleted	
5.1.1.3	Deleted	

5.1.2	If the spacecraft rolls about two axes for MAG calibration the ER also shall be turned on.	MAG24
5.1.2.2	The MAG experiment requires the acquisition of continuous data throughout the mapping phase of the mission.	MAG25
5.1.4.1	Deleted	
5.1.4.2	Deleted	
5.1.5.3	Momentum dumping should not cause the spacecraft to exceed the pointing specifications stated in Section 4.3.5.	MOLA5
5.1.6.1	Data will be required during the cruise phase to test equipment, both on the spacecraft and at the DSN stations, and to test experimental procedures and software for both the atmospheric and gravitational investigations.	RS12
5.1.6.3	The spacecraft shall transmit X-band signals whenever the spacecraft is "visible" from Earth during DSN station passes allocated to the Mars Global Surveyor Mission and within the constraints of the spacecraft power system.	RS13
5.1.6.3	The transmissions shall include the interval for radio occultation experiments as defined in Section 5.3.6.	RS14
5.1.6.3	The TCS shall be configured such that the onboard USO serves as the frequency reference for the downlink carrier during emersion and immersion.	RS15
5.1.6.4	Simulations of atmospheric radio occultation experiments shall be performed to test and calibrate equipment both on the spacecraft and at the DSN. During these tests the spacecraft and participating DSN station should be in the same configuration as for the actual atmospheric radio occultation experiments.	RS16
5.1.6.4	At least two tests shall be performed at each DSCC.	RS17
5.1.6.4	In-flight tests shall be performed prior to acquisition of any occultation data to determine the warm-up time needed to achieve stable operation following a period in which the TCS has been turned off.	RS18
5.1.8.4.2	This investigation requires that instruments capable of making atmospheric and polar observations obtain such data in a nearly continuous manner at all times during the martian year.	IDS4

5.2.5.3	Data external to the MOLA required on orbit about Mars include the spacecraft engineering telemetry and command uplink relevant to MOLA. Additional data required include spacecraft attitude and control information relative to all three axes.	MOLA6
5.2.7	Housekeeping data shall be available to the TES team within 24 hours of transmission to the Earth.	TES10
5.3.6	Spacecraft sequences shall be designed by the Mars Global Surveyor Project in collaboration with the Radio Science Team.	RS19
5.3.6	The occultation observation interval shall include: the extinction of the signal by the surface of Mars, including 20 s of data taken while the spacecraft is geometrically behind Mars; data from the surface to 200 km altitude, a baseline interval (100 s) during which the signal from spacecraft to Earth passes above 200 km altitude; and an appropriate time pad on both ends of the interval just defined to protect against timing uncertainty.	RS20
5.4.1.1	Deleted	
5.4.2.1	Monitoring functions are required when the instrument is not powered up, such as sensor and instrument temperatures.	MAG26
5.4.2.1	The overall maximum acceptable bit error rate to the magnetometer experiment is 10^{-5}.	MAG27
5.4.3.1	Bit error tolerance for compressed MOC data is 10^{-6}.	MOC10
5.4.4.1	Deleted	
5.4.5	The required digital data rate for MOLA, including packet overhead, is constant at 618 bits/s.	MOLA7
5.4.6	Telemetry from the spacecraft shall either contain or be sufficient for determining the physical state of the spacecraft, the USO operating status, non-gravitational forces on the spacecraft, and the TCS operating status.	RS20
5.4.7.1	In addition to the 688- and 1664-bits/s record rates, it is required that TES have the capability to downlink data in a real-time mode.	TES11
5.4.7.1	A rate of 4992 bits/s is required during each real-time orbit to return these data.	TES12
5.4.7.1	The bit error tolerance for the TES downlink is 10^{-5}.	TES13

5.5.1.3	Deleted	
5.5.3.4	Daily upload bit requirements vary from a low of 1.5 kb during low-rate record-only periods to 32 kb during high-rate record and realtime periods.	MOC11
5.5.3.4	Daily update bit requirements vary from a low of 0.8 kb during low-rate record-only periods to 16 kb during high-rate record and realtime periods.	MOC12
5.5.3.5	MOC requires that the uplink bit error rate be better than 10^{-5} received by the MOC.	MOC13
5.5.4.1	Deleted	
5.5.4.3	Deleted	
5.5.6.2	When the DSN is tracking the spacecraft, the Radio Science experiment will require the execution of six commands per orbit.	RS22
5.5.6.3	The execution of preprogrammed commands shall be to an accuracy of better than 10 seconds (3σ).	RS23
5.5.7.1	12 16-bit words/orbit or 145 words/day will be routinely required for TES commanding. Additional uplink capability will be required to update the tables at 2-to-4-week intervals.	TES14
5.6.1.1	The tracking of the mapping orbit should be as regular, continuous, and complete as possible, using as many DSN sites as practical; at least one pass per day with a 34-m antenna is required.	RS24
5 . 6 .1. 2	Media calibration data concerning the local environment of the DSCC are required to support the Radio Science investigations.	RS25
5.6.1.2	Supplementary calibration data are needed to characterize equipment performance (system noise temperature) and the experimental geometry (antenna elevation angle).	RS26
5.6.1.2	These calibration data shall appear as a file (or files in the MGS Project data base in a format TBD.	RS27
5.6.1.2	The DSN shall provide a Timing and Polar Motion File containing best estimates of the rotation rate and pole vector of the Earth.	RS28
5 . 6 .1. 2	Selected ground monitor data shall be processed and displayed in real time whenever the spacecraft is tracked for purposes of Radio Science calibrations or experiments.	RS29

5.6.1.3	The observations shall be performed under the following conditions: two-way coherent tracking mode; ranging channel on; recording of closed-loop data; Doppler sample rate of 1 sample per 10 seconds; recording of ranging data at a rate of one sample per 10 minutes.	RS30
5.6.1.3	Subreflector focusing shall be performed in a manner that is consistent with the Doppler noise goal given above.	RS31
5.6.1.3	The DSN should strive to minimize the time required to lock up in the two-way Doppler tracking mode following any period in which the spacecraft signal is absent or referenced to the onboard USO.	RS32
5.6.1.3	Radio metric data shall be provided in the form of Archival Tracking Data Files and Orbit Data Files.	RS33
5.6.1.4	The DSN shall acquire data from all occultations of the spacecraft by Mars that occur within DSN station passes allocated to the Mars Global Surveyor Mission.	RS34
5.6.1.4	The observations shall be performed under the following conditions: telemetry modulation off; ranging channel off and VLBI channels off; onboard USO as frequency reference for downlink signal during all occultation events; recording of open-loop data; recording of closed-loop data; Doppler sample rate of 10 samples per second.	RS35
5.6.1.4	The MOS shall provide the DSN with orbit ephemeris predictions, including occultation event times, 5 days in advance of the relevant station pass.	RS36
5.6.1.4	The DSN shall then generate Radio Science Prediction on the basis of this ephemeris with guidance from the Radio Science Team.	RS37
5.6.1.4	The DSN shall provide the Radio Science Prediction to the MGS Project Data Base 3 days in advance of the applicable station pass.	RS38
5.6.1.4	The Radio Science System shall be capable *of* storing the tuning predictions for up to 3 days in advance of the applicable tracking pass.	RS39
5.6.1.4	The start and stop times of all recordings shall be commanded by the Radio Science Predictions.	RS40

5.6.1.4	During each occultation event the Radio Science System shall digitally record the output of the open-loop receiver with a data information bandwidth of 0.2 to 2 kHz (value TBD).	RS41
5.6.1.4	The sampling rate shall be at least twice as large as the data information bandwidth.	RS42
5.6.1.4	All steps involved in acquiring radio occultation data at the DSCC and transferring these data to the Project Data Base shall be reliable enough to ensure that 95% of the data acquired is "error free". The requirements should be interpreted in the sense that data acquired from 19 out of 20 occultation events shall be recorded and delivered with a bit error rate of 10^{-7} or less.	RS43
5.6.1.4.	During all occultation experiments, pointing control of the ground antennas shall be accurate enough to limit any resulting variations in the intensity of the received X-band signal to a peak-to-peak level of 0.1 dB or less. Such pointing must be performed without the use of any signal-level feedback mechanisms.	RS44
5.6.1.4	The position of the subreflector shall remain fixed within all occultation observation intervals (duration 5 minutes).	RS45
5.6.1.4	After calibration, the overall amplitude stability of all DSN equipment involved in open-loop recordings shall be 0.1 dB or less over a period of 5 minutes, independent of both antenna pointing and any experimental effects on signal level.	RS46
5.6.1.4	The signal-to-noise spectral density of all equipment involved in open-loop recordings shall be greater than 75 dBc per Hz within 2000 Hz of the carrier.	RS47
5.6.1.4	Simultaneous to the acquisition of open-loop data during the occultation experiments, one-way Doppler data shall be generated in the form of radiometric data and transmitted in real time to the Project Data Base.	RS48
5.7.1	Deleted	
5.7.2	For the EDR/SPICE data transferred electronically to GSFC, the transmission rate should be at least 4 times the MAG data acquisition rate.	MAG28
5.7.2	EDRs should be made available to GSFC within 30 days of the acquisition of data.	MAG29

5.7.2	Final SPICE data, including attitude and spacecraft position information, should be sent to GSFC within 30 days of acquisition of data.	MAG30
5.7.3.1	All MOC data shall be delivered by the Project to the MOC Operations Facility at a rate commensurate with that at which it is returned from the spacecraft.	MOC14
5.7.3.1	The appropriate and/or available SPICE kernels are required within 14 days of this data delivery.	MOC15
5.7.3.1	MOC requires that data delivery be nearly continuous.	MOC16
5.7.3.2	All data must be delivered within 24 hours of ground receipt.	MOC17
5.7.3.3	All MOC image data must be recallable within 30 days of delivery to the MOC Operations Facility.	MOC18
5.7.4	Deleted	
5.7.5	This investigation requires that 95% of the experimental data records received at the ground stations be returned with no data gaps or record losses exceeding one packet in length.	MOLA8
5.7.6	The Project shall take those actions necessary to reduce data load from the occultation measurements to a minimum.	RS49
5.7.6	The closed-loop EDRs shall be delivered to the Project Data Base in the form of Archival Tracking Data Files and Orbit Data Files.	RS50
5.7.6	The open loop Experiment Data Records shall be electronic files in the MGS PDB.	RS51
5.7.6	A copy of each prediction set shall be made available to Radio Science investigators in electronic form on the mission data base 3 days in advance of the applicable tracking pass.	RS52
5.7.6	The spacecraft engineering data shall be an electronic file on the MGS Project Data Base.	RS53
5.7.6	The DSN shall deliver media calibration data on the Earth's ionosphere and troposphere and supplementary calibration data concerning DSN equipment to the MGS Project Data Base for all Radio Science data types.	RS54

5.7.6	Hard-copy records of NOCC logs and DSN station status printouts shall be required from the DSN on request.	RS55
5.7.6	Mapping orbit ephemeris prediction shall be generated by the Navigation Team for purposes of experiment planning and for use by the DSN in computing Radio Science predictions.	RS56
5.7.7	The quality requirements are for a bit error rate within the spectra, as received at the data processing facility at ASU, of 10^{-5} or better.	TES15
5.7.7	The data must be 85% complete in order to accomplish the mapping of the TES experiment. Data gaps should be randomly spaced (goal), with no single gap of more than one orbit.	TES16
5.8.2	SPICE prediction information should be made available to the MAG experiment at least 60 days in advance of anticipated events or mission phase starting date.	MAG31
5.8.3	Certain mission planning aids are required from the Project by the MOC: mission sequence plans, mission sequence schedules, and orbit/viewing forecasts. A schedule of Project and spacecraft events and accurate orbit determination predictions must be available before the actual MOC observations can be planned. Of particular importance is information on commanding opportunities for periods from approximately 30 days prior to execution through 3 days prior to execution.	MOC19
5.8.3	Predictions of ground tracks should be available at all times, and updated during the planning process as orbit determination permits.	MOC20
5.8.3	These planning aids should be available in work-station compatible computer code, with a relatively simple hard copy back up capability.	MOC21
5.8.3	The operational software must be available in time to support creation of the MOC-specific software.	MOC22
5.8.3	The offset of spacecraft time from UT must be provided to an accuracy of at least 20 ms once every 7 Earth days, in support of the sequencing activity.	MOC23
5.8.4	Deleted	

5.8.5	We require: orbit prediction data; attitude data from the spacecraft; predicted and determined footprint information from other instruments; time tags and selected data as provided by the MOC and TES.	MOLA9
5.8.6	RS requires: a table listing the predicted areocentric latitude, longitude and radius of Earth occultation points throughout the mapping phase of the mission; views of Mars showing the locations of the Earth occultation points and including pertinent surface features, such as the estimated locations of the polar cap boundaries; a DSN schedule of station coverage and antenna location for the mission including significant event times the maximum elevation angle and the Mars-Earth-Sun angle from each station pass; predicted times of immersion and emersion for all Earth occultations; telecommunications link predictions, including expected signal strength and Mars-Earth-Sun angle; plots of ground tracks on Mars maps with time tags of events.	RS57
5.8.7.3	Standard predictions of orbit information at 30-day intervals will be required for planning.	TES17
5.8.7.3	To aid in mission planning a variety of software tools are required: groundtrack projection on sinusoidal equal area projections and on a perspective view of the planet; the position of the Sun relative to the spacecraft reference frame at all points in the orbit; multiple overlays and combinations of groundtracks and previous observations; software for planning mosaics including variations in spacecraft altitude and orbital velocity using the digital photomosaic for targeting.	TES18
5.8.7.3	The following digital data bases are required: the USGS-generated digital photomosaic; digital topographic information.	TES19
5.8.8.2	The following are needed for planning at the start of each planning cycle: orbit track overlays on digital data base; illumination conditions along orbit track; previously acquired data in both digital and analog (map) format (goal); Viking-based digital imaging data base.	IDS5
5.8.8.4	The Project shall install and maintain a mission planning and data communications workstation and communications link at each IDS facility.	IDS6
7.1.1	Deleted	

7.1.2	Updated, standard SPICE files are required whenever the orbit/trajectory parameters, as predicted by the current SPICE do not meet the accuracy criteria stated elsewhere in this document.	MAG32
7.1.3	The Project shall provide support (partial salary support, office, travel, and operations support) for the MOC Experiment Representative and Instrument Engineer.	MOC24
7.1.3	The Project shall provide a microcomputer workstation for uplink/downlink activities including maintenance support, and one or more high-baud-rate communication lines (with support) to the MOC Operations Facility.	MOC25
7.1.3	The Project shall provide support for all quick-look analyses, facilities, offices, and data products required by the Project and/or NASA in support of activities associated with Public Information, Public Affairs and press conferences.	MOC26
7.1.3	The Project shall provide support for the publication of the initial and final reports of the MOC scientific investigation.	MOC27
7.1.4	Deleted.	
7.1.5	The Project shall provide the data link hardware and software for data communication between the Project Data Base and the MOLA PI.	MOLA10
7.1.5	The Project shall provide the hardware and software for creating command sequences which direct the spacecraft CDU/PDS to issue commands to the MOLA.	MOLA11
7.1.5	The Project shall provide the capability for transferring data between the SOPC and a GSFC computer used for reduced data record processing.	MOLA12
7.1.5	The Project shall provide the telemetered MOLA EDR, SPICE information and software tools for evaluating this information, and spacecraft engineering data.	MOLA13
7.1.5	The Project shall provide a database of other instruments' data and the necessary software for accessing these data (subject to interexperiment negotiation).	MOLA14
7.1.5	Deleted.	
7.1.5	The Project shall provide for the transmission of properly documented reduced MOLA data to an archive.	MOLA16

7.1.5	The Project shall assume responsibility for providing a database for MOLA reduced data products to other investigators.	MOLA17
7.1.5	The Project shall provide an end-to-end mission operations system test prior to the mapping mission that allows exercise of the Project-provided SOPC.	MOLA18
7.1.5	The Project shall provide a log of momentum wheel dumps.	MOLA19
7.1.5	The Project shall provide time tags and positions for all Earth occultation egress and ingress events.	MOLA20
7.1.5	The Project shall provide for full commanding of the MOLA at the spacecraft contractor facility after payload integration.	MOLA21
7.1.6	The radio science team will require routine monitoring of DSN Tracking and Radio Science System performance.	RS58
7.1.7	The Project shall provide: Experiment Representative support, including salary, office space, operations, and travel to attend TES Team Meetings and other designated meetings.	TES20
7.1.7	The Project shall provide: Instrument Engineer support including salary, office space, operations, and travel to attend TES Team Meetings, spacecraft interface meetings, engineering reviews at SBRC, etc.	TES21
7.1.7	The Project shall provide direct access of the Project Database at JPL.	TES22
7.1.8.1.5	Deleted.	
7.1.8.1.5	The system should support remote queries, orders, and delivery of appropriate data for the PSG.	IDS8
7.1.8.1.6	The Project should distribute in digital form a global Viking digital image mosaic for use in analyses of Mars Global Surveyor data.	IDS9
7.1.8.1.7	The Project should be able to accept into the Project database highly derived digital maps that show, for example, the abundance of particular weathering products.	IDS10
7.1.8.1.8	A modern electronic network that allows direct access to TL, PI, IDS, and Project personnel should be implemented.	IDS11

7.1.8.2	The Project should provide access to evolving standard MGS data bases for each instrument in such a manner that cross-correlation between data from different instruments can be effected.	IDS12
7.1.8.2	An office should be provided in the operations support area.	IDS13
7.1.8.2	The operations support area should have appropriate facilities for accessing the data base and for displaying data acquired to date by all instruments consistent with SOPC requirements.	IDS14
7.1.8.4	The project shall provide a forum through the PSG for negotiations with the instrument PIs/TLs for access by the IDSs to data from each instrument on a timely basis, and for participation by the IDSs in appropriate instrumental investigations.	IDS15
7.2.1	Deleted	
7.2.6.2	The Project workstation shall be compatible with the UNIX operating system and Ethernet TCP/IP or other standard protocols and will support program development and execution in 'C', Pascal, and Fortran languages.	RS59
7.2.6.2	For team operations electronic access from Stanford and JPL to the Project database will be required 24 hours per day over the active period in martian orbit.	RS60
7.2.7.2	It is required that all software required to manipulate NAIF/SPICE kernels and to support reconstruction of the full instrument pointing geometry will be provided by the Project.	TES23
7.2.7.2	It is also required that the Project will supply all of the uplink planning hardware and software and the downlink communication software and hardware necessary to handle the estimated 56-kbps data transfer rates to and from the Project Database.	TES24
7.2.8.4	Rapid turnaround (<30 min.) communications with other IDSs and with PIs and TLs through their workstations/PDB is required.	IDS16
7.2.8.4	Display of any on-line data or data product is required by the workstation.	IDS17
7.2.8.4	Display of the orbital information for any or all prior times during the mission by the workstation is required.	IDS18

7.2.8.4	Display of orbital groundtrack and SPICE information as planned for the next 60 days by the workstation is required.	IDSl9
7.2.8.4	Display of the planned mode of operation for each instrument for the next 30 days by the workstation is required (if provided by PI, in SPICE kernel).	IDS20
7.2.8.4	Display of the groundtrack beneath the transmittal ray line of sight for radio occultations where the ray is beneath 50 km altitude for the tangent point being at the surface, for all previously occurring occultations, and for those planned for the next 60 days by the workstation is required.	IDS21
7.2.8.5	Key attributes of the workstation should include a high-speed link to JPL.	IDS22
7.2.8.5	Key attributes of the workstation should include communication with the Ames Space Science Division's VAX computer.	IDS23
7.3.5	MOLA requires the digital terrain model and digital image model.	MOLA22
7.3.5	MOLA requires the gravity field derived by the Radio Science investigation.	MOLA23
7.3.5	MOLA requires all Doppler tracking and range data and associated calibration data.	MOLA24
7.4.2	The data system shall support mission operations, production of Standard and Special Data Products, and science analysis, using a geographically distributed approach.	IDS24
7.4.2	Mission operations personnel at JPL shall take the modified skeletal sequences for each 28-sol planning cycle for each instrument and integrate them into an uplink package.	IDS25
7.4.3.1.1	The Project Database shall maintain digital versions of EDRs, SPICE files, and Standard Data Products to be acquired and/or produced during the full Mars year of observations. EDR and SPICE data will occupy approximately 84 Gbytes; SDPs to be deposited into the PDB will occupy approximately 464 Gbytes.	IDS26
7.4.3.1.3	Standard Data Products within the PDB shall be in Planetary Data System-compatible formats, with PDS labels.	IDS27

7.4.3.1.5	EDR and SPICE data for a given instrument once in the PDB shall be delivered to the relevant TL or PI within 24 hours of request by the TL or PI for data.	IDS28
7.4.3.2.2	The leader of an investigator group (PI, TL, or IDS) shall access approximately 100 Gbytes of the PDB.	IDS29
7.4.3.2.4	Approximately 50% of the SPDPs deposited within the PDB shall be accessed by the TLs, PIs, and IDSs.	IDS30
7.4.3.3.1	Spacecraft engineering telemetry, instrument EDRs, and SPICE information shall be transferred from the PDB to the Planetary Data Systems six months after the receipt of the EDRs and associated SPICE files by the MOS, unless observations must extend over a longer time period to be able to generate the relevant data products.	IDS31
7.4.4	During the first six months after receipt of EDRs any use and analysis of data from a particular experiment or use of the results of unpublished papers derived from such analysis will require the agreement of the appropriate Principal Investigator or Team Leader.	IDS32
7.4.5	Press Information Office Products should be approved by the Project Science Group or its designated subgroup before release to the Press Information Office.	IDS33
5.1.1.2	Deleted	
5.1.3.1	Moisture bakeout procedures, which include calibration tests, shall be performed for the MOC during early cruise.	MOC28
5.1.3.3	The MOC requires calibration tests to be conducted before and after moisture bakeout during early cruise. These tests consist of a series of star images taken with the spacecraft spinning about the Y-axis.	MOC29

3. TRAJECTORY REQUIREMENTS

3.1 MAPPING ORBIT PARAMETER REQUIREMENT SUMMARY

Requirement	Desire
350±50 km semi-major axis difference from Mars equatorial radius Maximum altitude variation of 105 km. Minimum altitude of ≥250 km Maximum altitude of ≤540 km	3- or 7-day repeat cycle
Ground track separation 1/3-1/20 altitude	Ground track offset ≤2 km
Sun synchronous (2 p.m.)	<377-km surface altitude
≥10 mapping cycles	56-day cycle offset 2 or 10 km
Repeat period ≠multiple of solar rotation Near polar (±3°); near circular (±0.05) orbit	Late mission shift to morning Sun-synchronous period

3.2 MAPPING ORBIT PARAMETERS

3.2.1 Deleted

3.2.2 Magnetometer (MAG)

3.2.2.1 **Acquisition of data during the initial drift orbit is a requirement (MAG1). An orbit with a period of approximately one day shall be maintained for a period of at least 28 days (MAG2)**. This will provide essential data to map the martian bow shock and related solar wind interaction boundaries. These data are of high value in the interpretation of further observations by the Mars Global Surveyor spacecraft and will allow the differentiation of fields intrinsic to the planet from those induced by the interaction with the solar wind.

3.2.2.2 **The difference between the spacecraft orbital semi-major axis and the equatorial radius of Mars is required to be 350±50 km (MAG3).** The orbit altitude should be sufficiently small to permit the detection of weak fields of planetary origin without ambiguity. The required orbit is adequate to accomplish this objective.

3.2.2.3 **It is required that the ground track separation between successive repeat period orbits be from 1/3 to 1/20 of the orbit altitude (MAG4). The ground repeat period must not be a small multiple (i.e., commensurable) of the solar rotation period (26.354 Earth days as seen from Mars). (MAG5).**

3.2.2.4 **The minimum required number of mapping cycles is 10 (MAG6)** to establish with confidence the nature and origin of the observed magnetic fields. To significantly enhance the detection accuracy of weak crustal magnetic signatures, the number of mapping cycles should be maximized consistent with overall mission constraints.

3.2.2.5 **It is required that the average mapping orbit be fixed in local time (MAG7)** to minimize the impact of large scale ionospheric currents on the observations. Although the optimal mapping orbit for the magnetic field investigation is one fixed at the dawn-dusk meridian, the anticipated 1400 hrs local time orientation for the Mars Global Surveyor orbit allows the accomplishment of the principal scientific objectives.

3.2.3 Mars Orbiter Camera (MOC)

3.2.3.1 **It is required that the altitude of the spacecraft above the true surface of Mars be kept under 540 km (MOC1)**. The MOC requires as low an orbit as possible for maximum spatial resolution. The proposed resolution of the MOC (1.4 m/pixel) is met whenever the spacecraft is below 377 km. The narrow-angle optical resolution is worse than 2 m/pixel at all altitudes above 540 km.

3.2.3.2 The MOC may acquire adjacent strips of high-resolution images of select areas during the mission near the equator. The 2.8-km nominal width of the narrow-angle system suggests that the spacing of the orbits be less than 2 km [allowing 25% overlap or variation in pointing of 2 milliradian (mrad)]. There are two orbital mechanisms by which such spacing might be achieved:

(1) the spacecraft can be placed in an orbit such that the ground track offset distance for each walk cycle is <3 km (as opposed to the nominal mission value of 30 km), or

(2) the 56-day mapping cycle (the "Supercycle") ground track offset can be maintained at <3 km.

There are major advantages to (1), (e.g., allowing the mosaic to be made in a short period of time under consistent seasonal conditions), while it may be difficult to achieve the required accuracy over the extended periods implied by the latter.

3.2.4 Deleted

3.2.5 Mars Orbiter Laser Altimeter (MOLA)

3.2.5.1 **It is required that the MGS orbit be nearly polar (i = 90º ±3º, 3σ) (MOLA1). The orbit shall be nearly circular with altitude variation not to exceed 105 km (MOLA2)** (preferably lower). The ground track should be controlled such that uniform coverage of the surface is obtained by the end of the mapping phase of the mission.

The current baseline with a 3-day repeat cycle, 30-km orbital walk, and 56-day mapping cycle is acceptable.

3.2.6 Radio Science (RS)

3.2.6.1 **It is required that the orbital periapsis altitude be between 250 km and 400 km (RS1).** In general, the Radio Science Investigation requires low-altitude polar orbits of Mars; these provide good sampling of the gravitational field and frequent radio occultations over most of the martian year. Precise values of orbital altitude are not critical, but lower altitudes are highly preferred for gravity investigations. Toward the lower extreme, the orbit should not expose the spacecraft to significant atmospheric drag forces ($\sim 5 \times 10^{-8}$ ms^{-2}), which gives a lower limit of about 250 km for the periapsis. On the other hand, orbits with a periapsis altitude greater than about 400 km would degrade the resolution in the maps of the gravitational field, and would seriously compromise Radio Science objectives in this area. With regard to occultation events, the quality of these observations is not overly sensitive to orbit altitude for any value below about 1000 km.

3.2.6.2 **The Radio Science Team requires a gravity calibration orbit (GCO) immediately preceding initiation of the mapping phase essentially the same as the mapping orbit but with a repeat cycle of 7-10 days (RS2)**. For values in this range, each repeat cycle provides fast, even coverage of Mars with a ground-track spacing that nearly matches the resolution of the gravity measurements (~200 km as limited by the spacecraft altitude). **The spacecraft shall be tracked continuously (24 hours per day) over at least one full repeat cycle (RS3)**, and preferably throughout the bias orbit, the GCO, and the spacecraft checkout period. The resulting data would be sufficient for derivation of an improved, high-resolution model for the gravitational field, which constitutes once central objective of the MGS Mission. Progress toward this objective early in the mapping phase would also enhance navigational capabilities, yielding more efficient mission operations as well as higher quality in the initial results from all MGS instruments that require an accurate knowledge of the trajectory.

The Radio Science Team has no strong preference as to the choice of repeat cycle duration for the mapping phase. However, in the interest of the gravity investigation, it is highly desirable that the mission include several periods of intensive tracking that complement the observations during the GCO. The intent here is to acquire fast, even tracking coverage of Mars for different values of the angle between the orbital plane and the Mars-Earth line, as shown in Figure 5-1. During the GCO, this angle is expected to be about 45º (TBD). The first "gravity campaign" of the mapping phase is desired when the angle is 0º, near day October 29, 1998. During this campaign, the spacecraft should be tracked continuously over a full repeat cycle at three separate times whose spacing is one third of a mapping cycle. (For example, with a repeat cycle of 3 days and a mapping cycle of 56 days, the campaign consists of 3 periods of continuous tracing, each 3 days long, with a spacing of 56/3 days.) This strategy should yield tracking data whose quality and combined coverage approach those of the GCO, without imposing any constraint on the choice of repeat cycle duration. Furthermore, the GCO and campaign #1 are highly complementary in that the former provides good coverage of the north pole, while the latter covers the south pole (see areocentric latitude of Earth, also shown in Figure 5-1).

A second gravity campaign, whose implementation is the same as the first, is desired when the orbit-plane angle reaches its maximum value of 65º, near day TBD. At this time, MGS should be observable continuously from Earth for several weeks.

These periods of intensive tracking (GCO, 1, and 2 of Figure 5-1) are particularly important to the gravity investigation. If continuous tracking is not possible in these periods, then the available tracking coverage should alternate among the DSN stations to avoid difficulties in data reduction associated with the exclusive use of a single tracking station (see Section 4.8 for further discussion).

3.2.7 Thermal Emission Spectrometer (TES)

3.2.7.1 **It is required that the altitude of the spacecraft be maintained between 250 km and 2000 km (TES1).** The TES instrument is designed to a nominal orbit semi-major axis-radius of 361 km. The primary constraints on orbit parameters are: (1) the required contiguity of the fields of view projected onto the surface during the mapping phases; and (2) the removal of image smear produced by spacecraft motion during the acquisition of a single spectrum.

3.2.7.2 **It is required that each mapping cycle (56 days) be offset by more than 9 km in a consistent direction to permit the TES to observe the entire planet**

(TES2). Exact repeat of mapping cycles would result in redundant observations and 21-km-wide gores, given that the TES FOV is only 9 km wide.

Precise, contiguous coverage degrades slowly at altitudes below 361 km. At all altitudes above the nominal, the TES instrument operates in its normal mapping mode, with additional overlap between sequential IFOVs.

The TES provides its own internal image motion compensation using the pointing mirror. The pointing mirror motion rate is software commanded and adjustable, allowing smear removal at any operational altitude. In order to simplify mission operations, it is preferred that the motion rate of the pointing mirror be constant within a single orbit. This operational requirement can be met provided that the smear caused by a variable ground velocity within an orbit is less than +10% of a field of view. For elliptical orbits this can be met given that the ground velocity varies by less than +0.4 mrad/s about the mean. This constraint can be easily met even for elliptical orbits up to a minimum altitude of 250 km and a maximum altitude of over 2000 km. In any circumstance the mirror velocity is commandable throughout the orbit if necessary.

3.2.8 Interdisciplinary Science (IDS)

3.2.8.1 Arvidson. A near-polar, Sun-synchronous, low-altitude orbit is required (IDS1). The mapping cycle should be as brief as possible (IDS2), preferably 3 sols.

3.2.8.2 Carr. It is desired that the ground track is offset from that at the start of the previous cycle by a distance comparable to the highest resolution mapping instrument (about 2 km), so that the entire planet is ultimately covered at the resolution of the highest resolution mapping instrument. The basic goal is to characterize the chemical and physical properties of the surface of the entire planet at the maximum possible spatial resolution. Because of downlink constraints, more realistic goals are the mapping of the entire surface at some intermediate spectral resolution and characterizing every identifiable terrain or spectral unit at the maximum possible resolution. The progressive delineation of the surface properties should be accomplished in such a manner that gaps are not left as a result of seasonal interruptions such as could result from dust storms and the deposition and removal of volatiles at high latitudes. The requirement to characterize, at high spectral and spatial resolution, each identifiable unit on the planet is best met with an orbit that beats with the times of high-rate downlink (nominally 3 days). In this way contiguous high resolution coverage can be locally assembled. These requirements will be satisfied by a circular orbit at 360 km altitude with Q = 12-2/3, but other orbit parameters are possible.

3.2.8.3 Ingersoll. On the question of orbit repeat cycles, any cycle that rapidly fills in the spaces left by the preceding day's orbits is good. This strategy ensures the maximum possible longitude resolution in the shortest possible time, which is important for observing rapidly-changing patterns in the atmosphere. Repeat cycles of 2, 3, 5, and 7 days all fit this criterion, but for 5 and 7 day cycles it is best to jump around from day to day within the 30-degree longitude interval rather than march monotonically across it. If high-altitude orbits save mass by making the quarantine requirement easier, then they are preferable if everything else is equal.

3.2.8.4 Jakosky. **The orbit required for this investigation is near-circular and Sun-synchronous, with a dayside equator crossing near 2 p.m. mean local solar time, and with an orbital altitude between 350 and 450 km (IDS3).** The orbit shall be non repeating, in the sense that the equator crossing on each successive orbit after a nominal 3- or 7-day repeat cycle shall pass over a location that is separated from that of other orbits.

For the purposes of this investigation, there is no difference between a northward- and a southward-traveling motion for the dayside equator crossing.

3.2.8.5 Haberle. To provide the capability of maximizing the diurnal coverage, it is highly desirable to be able to shift the orbit of the spacecraft from an afternoon viewing nadir geometry to a morning viewing geometry without damaging either the spacecraft or instruments. Such a shift represents a potential late mission maneuver.

3.3 NAVIGATION

3.3.1 Deleted

3.3.2 Magnetometer (MAG)

The desired reconstructed accuracy of the spacecraft position and attitude knowledge are 3 km along track, 2 km across track and ±0.25 degrees respectively. The S/C position should be referenced to the center of the planet and the attitude to the geographical martian centered coordinate system of date.

3.3.3 Mars Orbiter Camera (MOC)

3.3.3.1 The MOC desires an update of S kernel and equator timing three days in advance. In order to achieve the most important science objectives at the lowest use of data rate and mission planning and operations resources, it desires the following capabilities:

Cross-Track	≤ ±1.0 km
Along-Track	≤ ±1.0 km
Event Timing	≤ ±0.3 s

The MOC data themselves may be used to achieve this navigational accuracy, locating the spacecraft with respect to surface features, and permitting refinements to the navigation computations. These goals are not inconsistent with the Longitude Grid Control concept, provided that the Project makes a concerted effort to reduce gravity field uncertainties, atmospheric drag effects, and orbit sustenance maneuver execution errors, which it may do through the following actions:

1. Conduct a geodetic control experiment by acquiring simultaneous gravity and optical navigation observations. MOC would implement its portion of the geodetic experiment by acquiring global coverage using the wide angle camera at its intrinsic resolution (~250 m/pixel). There are three navigation advantages to acquiring these data:

    a. Simultaneous observations permit gravity field specification in body-fixed rather than solely inertial coordinates. This should, in turn, allow multiple observations to break biases that result when each area is observed only at one line-of-site geometry, thus significantly improving the gravity model.

    b. Reducing the gravity field uncertainty results in a similar reduction in the error in the LGC. The Projected Navigation Team estimates that about one-third of the LGC error [~1 km (1σ)] results from the gravity field uncertainty.

    c. The geodetic control observations would permit positional accuracies post facto of at least 1 km, and perhaps as good as 0.5 km, if tied to the Viking Lander 1 network.

2. Conduct optical navigation observations throughout the mission to address atmospheric drag. With better gravity and burn error models, repetitive imaging directly addresses the contribution of atmospheric drag (such drag will be the only remaining consistent trend in the data). In practice, the atmospheric effect could be empirically minimized, as the positional information derived from the images could be incorporated into the calculations used to establish the orbit sustenance maneuver parameters.

Assuming the gravity, maneuver, and atmospheric drag errors could each be reduced by about 50%, the RSS uncertainty would be 1 to 1.5 km, within the range required above.

Among the reasons for this predict capability goal is the objective to image the Viking Lander sites, which can be accomplished provided the along-track error in prediction does not exceed ±10 km and that the LGC cross-tracking uncertainty is ≤1 km.

3.3.3.2 **The MOC requires accurate orbit position and timing re-construction (MOC2)**, although the use of context imaging provides the instrument with an independent means of determining target body coordinates. It recommends that the 3-day predict and post facto reconstruction be of comparable accuracy: As noted above, the MOC data can be used to achieve this level of knowledge provided the geodetic control and optical navigation observations are made during the mission.

3.3.4 Deleted

3.3.5 Mars Orbiter Laser Altimeter (MOLA)

For accurate correction and positioning of the altimetric data, MOLA requires accurate information on the ground track and pointing of the spacecraft, and accurate timing information. Precise orbit determination will be done as part of this investigation. Information desired from the Project includes:

(1) All spacecraft tracking data, USO data, time tags, and aerographic coordinates of sub-spacecraft track;

(2) Spacecraft in-orbit position knowledge to 5 km along track, 2 km cross track, 0.5 km radially;

(3) Spacecraft pointing knowledge to 3 mrad in each axis;

(4) Location and time tags for all occultation events (including output from the USO);

(5) Correlation of spacecraft time with UTC to within 5 ms is strongly desired.

In addition, the cross track position of the sub-spacecraft point should be controlled to +1 km and the orientation of the spacecraft with respect to the nadir direction should be controlled to within 10 mrad in each axis.

3.3.6 Radio Science (RS)

3.3.6.1 <u>Occultation Measurements</u>.

(1) Mapping Phase. **Mapping orbit ephemeric predictions shall be provided by the MOS to the DSN 5 days in advance of the events (RS4)** to allow for timely experiment planning. **These predictions shall include the times (at both immersion and emersion) when the propagation path from spacecraft to Earth grazes the surface of Mars as well as the times when the propagation path is 200 km above the surface (RS5)**. For planning purposes, the effect of the atmosphere of Mars can be ignored in computing these event times. It is desired that the orbit predictions be accurate enough to forecast: i) the event times to within 10 seconds (3 σ), and ii) the frequency of the X-band carrier received from the spacecraft to within 300 Hz (3 σ). The accuracy of these predictions will determine the duration of the recording interval and the information bandwidth for data collection in the occultation experiments. If the 10-second and 300-Hz goals cannot be met, a longer recording interval and/or a wider bandwidth will be needed to achieve the same probability of success in obtaining the data. Performance at the 10-second/300-Hz level is strongly desired as it will result in easily manageable quantities of data. It is a goal that errors (3a) in the mapping orbit ephemeris reconstruction not exceed:

(a) 1 km in spacecraft position;

(b) 0.36 mm/s in the component of spacecraft velocity along the line from spacecraft to Earth;

(c) 0.007 mm/s^2 in the component of spacecraft acceleration along the line from spacecraft to Earth.

These goals apply only over the observation intervals of the atmospheric occultation experiments (about 5 minutes each for immersion and emersion).

(2) Orbit Insertion Phase. The occultation experiments impose no specific requirements on this phase of the mission. However, an accurate spacecraft ephemeris is needed during the mapping phase to avoid bias effects in reducing the occultation data, as reflected in the requirements given above for ephemeris reconstruction. Accurate knowledge of the spacecraft trajectory in turn requires a reliable model for the gravitational field. Such a model should be derived (at least in a preliminary sense) as early as possible, preferably late in the orbit insertion phase or very early in the mapping phase of the mission.

(3) Cruise Phase. The occultation experiment imposes no trajectory requirements on this phase of the mission.

3.3.6.2 Gravity Measurements.

(1) Mapping Phase. There is no particular requirement for navigation accuracy, as the gravitational field will be determined independently within this investigation.

(2) Orbit Insertion Phase. All radio metric data collected in this phase of the mission for purposes of navigation are requested to begin investigation of Mars' gravitational field.

(3) Cruise Phase. Radio metric data collected in this phase of the mission for purposes of navigation are requested for testing of investigation procedures and software.

3.3.7 Thermal Emission Spectrometer (TES)

This section describes the spacecraft positional requirements of the TES; pointing requirements are given in Section 4.3.7. Three periods for navigation requirements are identified; the cruise/approach, transition orbit, and mapping phases.

It is desired to obtain observations of the moons Phobos and Demos during the transition orbit. This period is optimal because of the long integration periods obtainable. From the periapsis point of the orbit, the ranges to Phobos and Demos are approximately 10, 100 and 23, 600 km, respectively, when the satellites are in the plane of the spacecraft orbit. At these distances the angular sizes of Phobos and Demos are 1 and 0.25 mrad respectively. Because they are smaller than a TES IFOV, the pointing requirements are determined by the TES IFOV, and are to point and maintain the satellite within the 3 x 2 array of TES detectors. Thus the pointing control must be ±4.1 mrad along and X and Y axes. The navigation capability must be consistent with this pointing requirement, including both knowledge of the spacecraft position and knowledge of the satellite ephemerides.

It is also desired to obtain observations of the martian surface and atmosphere during the transition orbit. The navigation requirements for these observations are for nadir viewing of the planet with a pointing control of 16 mrad and a pointing knowledge of 8 mrad. The control requirement translates to a 60 km downtrack and crosstrack error at a 360 km periapsis, and a 600 km downtrack and crosstrack error at a 35,000 km apoapsis . The knowledge requirement translates to a 30 km downtrack and crosstrack error at a 360 km periapsis, and a 300 km downtrack and crosstrack error at a 35,000 km apoapsis. Radial knowledge requirements are 50 km at periapsis and 500 km at apoapsis.

The third observing period is the duration of the mapping orbit. **During this mapping phase, surface and atmospheric observations will require a pointing control of ±10 mrad and knowledge of ±3 mrad about all axes (TES3). Prediction of the equator crossing time will be required within 25 km along track for the initiation of orbit sequence start (TES4)**. Updates of this position to within 10 km (99%) immediately prior to data acquisition are highly desirable. **Cross-track prediction of the spacecraft ephemeris will be required to within 10 km for planning of mosaic observations (see Section 5.1.7.2.1.3) (TES5). The radial prediction requirement is 25 km (TES6). After-the-fact reconstruction of the orbit ephemeris is required to within 9 km down-track and 5 km cross-track for surface feature identification. The radial requirement is 10 km (except when orbital inclination to plane of sky = 90°) (TES7).**

3.3.8 Interdisciplinary Science (IDS)

3.3.8.1 Arvidson. Knowledge of the locations of observations in terms of latitude and longitude should be no worse than the long term (after the fact) estimates given in the Projects Mission Plan Document.

3.3.8.2 Carr. After the fact, it is desired to establish to within 200 meters the position of the field of view of the instruments with respect to features observed in the Viking Orbiter images. The position of features on the surface with respect to the rotation axis and prime meridian are known to only 3-5 km, however, relative positions over local areas are known much more precisely, and the relative positions of MGS fields of view over local areas should similarly be determinable to much greater precision. For accomplishment of this investigation a goal is to determine relative positions of features within 1000 km of each other to within 200 meters. The expectation is that this goal will require feature matching between the Viking Orbiter images and the MGS science data. The requirement stems from the need to assess the possible mix of bedrock components within the various fields of view of the MGS instruments. Before the fact knowledge is less stringent and is guided mainly by the need to avoid gores in the coverage and to be able to time observations so as to make observations on specific features such as volcanoes, central peaks or crater streaks. For these purposes the desired pointing control should be around 2 km.

3.4 CRUISE/TRANSITION ORBIT

3.4.1 Deleted

3.4.2 Magnetometer (MAG)

Spacecraft maneuvers constitute a powerful calibration tool for magnetic field experiments, particularly in the case of spacecraft built with limited magnetic constraints. During the cruise and mapping phases, it would be highly desirable to perform spacecraft roll maneuvers about the reference axes a few times during the mission. It is plausible that these maneuvers could be integrated with attitude reaction or determination maneuvers. Rolls about the nadir-pointed axis during the mapping phase will allow the partial determination of effective zero levels for the magnetometers. The anticipated drift orbit geometry is particularly useful to map the martian bow shock and some of the magnetotail boundaries. The drift orbit should be oriented at a local time of 1200 hrs +2 hrs and it is a goal that its apogee should be such that the spacecraft traverses the martian bow shock twice per orbit, with at least one crossing occurring within the range of 1.2 to 2 martian radii. **It is required that the spacecraft remain in the drift orbit for at least four weeks prior to final mapping orbit insertion, and that data be acquired continuously during this period (except during maneuvers) (MAG9).**

Spacecraft charging and wake effects can affect the ER measurements. **The minimum requirement is for data collection by the ER during a portion of the cruise and drift phase orbits (MAG10).** During at least part of these times the ER should be out of the spacecraft wake. These data are needed for calibration and performance checks. The ER is also a powerful tool for measuring boundaries in the martian magnetosphere. It is requested that, along with the magnetometer, the ER acquire data continuously during the drift phase orbit. Since determination of these boundaries is based upon good low-energy thermal electron measurements, it is requested that the ER remain outside the spacecraft wake during this phase.

3.4.3 Mars Orbiter Camera (MOC)

Moisture bakeout procedures, which include calibration tests, will be performed for the MOC during early cruise. Other than permitting this procedure, the MOC places no constraints on either the cruise trajectory or the transition orbit. The MOC desires to operate in a nadir-fixed attitude at its real-time transmission rate for a total of 7 days of continuous (24 hr/day) Deep Space Network (DSN) tracking, in order to acquire simultaneous geodetic and gravity observations. This could ideally occur during the Gravity Calibration Orbit, provided the spacecraft is in a stable, nadir-pointing attitude.

The MOC has no operational requirements until after the spacecraft enters the Gravity Calibration or Mapping orbit. However, the MOC is capable of acquiring pre-MOI observations, should such observations be requested by the Project. There are two reasons why the Project may request that MOC acquire pre-MOI observations:

1. Science: Providing the spacecraft can be placed in an appropriate attitude and roll to move the planet through the MOC field of view, Mars would fill the narrow-angle field of view at a range of approximately 900,000 km, with a resolution of 3 km/pixel. This occurs approximately 4 days prior to MOI.

   Mars would be 100 pixels across at a range of 18 million km, about two months prior to MOI. These observations would permit monitoring of Mars prior to orbit insertion and mapping orbit operations.

2. Navigation: Providing the spacecraft can be placed in an appropriate attitude and roll, stars to TBD magnitude can be imaged to one pixel knowledge within the NA CCD (3.71 mrad). The NA FOV, 0.4°, makes its use in navigation a challenge. Coarse (0.6 mrad) pointing information can be acquired from the WA CCDs, over a 140° FOV. The principal limitation on the use of the MOC for pointing information is the uncertainty associated with its alignment with the spacecraft axes.

3.4.3.1 Orbital Maneuvers. The MOC desires a stable and well-defined orbit, with an ability to predict position with respect to surface features at the level noted in paragraph 3.3.3 above. Provided the Mars Global Surveyor Project meets these navigation requirements, MOC has no preference concerning orbital maneuvers. **The MOC requires that all maneuvers be announced sufficiently in advance to permit planning around their occurrence (MOC3).** Presumably, such maneuvers will occur at periapsis or apoapsis, in polar regions where observational redundancy should exist. However, should the Project not meet the navigation requirements noted above, the MOC can achieve comparable results provided that spacecraft orbital maneuvers are minimized. Maneuvers at intervals of two weeks or less will greatly inhibit MOC's efforts at navigation. Monthly maneuvers may be tolerable.

3.4.4 Deleted

3.4.5 Mars Orbiter Laser Altimeter (MOLA)

MOLA considers a gravity calibration orbit for a 7-day period during the transition phase to be desirable as a means of meeting the mapping orbit requirements for MOLA as described in Section 3.5.

3.4.6 Radio Science (RS)

See Section 3.3.6.

3.4.7 Thermal Emission Spectrometer (TES)

3.4.7.1 Deleted

3.4.7.2 Transition Orbit Requirements. For maximum science return from the mapping orbit, it is imperative that each team be intimately familiar with the performance of the individual instruments and with the complexities of mission operations. Experience with previous planetary missions has shown that actual flight operations experience is required, even for teams which have been technically well prepared. Instrument performance in orbit may differ from that during ground test; the ability of flight operations to effectively handle both routine and emergency situations is developed only under actual conditions. For these reasons, and because several significant scientific observations can also be made, it is desirable that limited science operations be conducted within the transition orbit.

Science observations during this time, with downlink of complete spectral information, will allow initial assessment of the major spectral characteristics of the Martian surface materials and setup of the on-board spectral editing tables for immediate use at the beginning of the mapping orbit. Science observations during this period will extend the baseline for determining the annual repeatability of seasonal processes. The transition orbit also provides an opportunity to observe the surface and atmosphere at different local time than will be available during the MGS mapping mission and to observe the season of maximum atmospheric water abundance. In addition, high SNR data can be obtained on the Martian satellites (particularly Demos) by making long integrations.

The transition phase science objectives can be addressed from a wide range of possible transition orbits. Mapping is not planned, so contiguous IFOVs are not required. Atmospheric monitoring and the collection of initial surface spectra for instrument checkout are preferred at altitudes near periapsis but can be performed at altitudes varying from 300 to 15,000 km. Some observations in the region from 40° S to 40° N are desired to obtain the maximum signal-to-noise ratio for instrument checkout. A periapsis in the northern hemisphere for the transition orbit is preferable, because it provides high spatial resolution for limb observations of the annual water vapor maximum, which occurs at high northern latitudes during the transition orbit period.

The navigation requirements for the transition orbit observations are given in Section 3.3.7. Spacecraft maneuvers are desired to orient the spacecraft with +Z axis pointed at the nadir and the +X axis pointed along the direction of motion during the time of each data acquisition. Real-time downlink of raw interferogram data acquired on the surface would be highly desirable during this period to allow rapid checkout of the instrument health and full verification of the on-board processor algorithms.

3.4.8 Interdisciplinary Science (IDS)

3.4.8.1 Haberle. During the transition orbit, it would be highly desirable to obtain atmospheric measurements of the planet at local times of day not covered during the nominal mapping orbit. Thus, care should be taken in the design of sequences and the quality of the navigation data (e.g., use of star sensor data) to insure that no instrument looks inadvertently at the Sun. It would be optimum to operate in a 3-axis (nadir) stabilized mode to permit continuous observations of the planet during the transition orbit.

4. SPACECRAFT REQUIREMENTS

The instruments' physical properties such as mass, power, fields of view and operating temperature are given in Appendix D. Due to the likelihood of changes to these detailed specifications, they are presented for information purposes only. Requirements derived from these properties must, therefore, be subject to the more current Instrument Interface Control Document (ICD).

4.1 LOCATION, ALIGNMENT AND FIELD OF VIEW

4.1.1 Deleted

4.1.2 Magnetometer (MAG)

4.1.2.1 Position on the Spacecraft. **The two triaxial fluxgate sensor assemblies shall be mounted to reduce the spacecraft stray field contribution to less than 3 nT with a maximum variability (DC to 10 Hz) of no more than +0.3 nT peak-to-peak (MAG11). This field should be dipolar in geometry.** In general, the magnetic field generated by a component or spacecraft subsystem can be considered to be "dipolar" in nature at a distance of 5 to 10 times the characteristic dimension of the device or subsystem.

The ER detector assembly consists of a hemispherical electrostatic analyzer (8 cm x 12 cm x 12 cm) with a 360° x 14° field of view (FOV) mounted to the detector electronics box (20 cm x 13.5 cm x 7 cm) with a serial interface to the magnetometer DPU. Requirements for the instrument's location on the spacecraft are as follows:

(1) The ER should be electrically insulated from the spacecraft so that small potential differences (<10 V) can be maintained.

(2) The spacecraft area surrounding the ER mount (±l meter) should be conducting and at the same potential as the ER.

(3) **The ER detector location should avoid areas of motor exhaust plumes (MAG13).**

(4) The detector location should preferably be outside the spacecraft wake (a cone of ~15-20° half angle) in the orbital velocity direction hemisphere.

The necessity of minimizing potential differences is driven by a science requirement to measure low photoelectrons (1-50 eV) and ionospheric thermal electrons (<1 eV). Low energy electron trajectories are distorted by the perturbing fields produced by the spacecraft. Spacecraft potentials of a few to 10 volts positive or negative are expected to occur to maintain current balance between the local plasma and the spacecraft. These potentials fall off rapidly with a scale size the order of the plasma debye length. Average ionospheric densities and temperatures of approximately 300/cm^3 and 0.3 eV are expected, giving a debye length of 0.25 m. Four debye lengths (1 m) reduce a 5 V spacecraft field to an acceptable 0.1 V. The low energy measurements also require that the instrument surface be close to the plasma potential. To accomplish this the ER must be electrically insulated from the spacecraft to allow small (<10 V) potential adjustments of the detector surfaces. We desire that ±l meter of the spacecraft area surrounding the ER mount be conducting and at the same potential as the ER to reduce distortions of particle trajectories passing near the spacecraft area.

The ER detector should be placed far from motor plumes to avoid contamination of the micro channel plate detectors by any hydrocarbons. The mounting should also avoid the spacecraft wake to assure that the low energy electrons have access to the instrument. A spacecraft moving through a cold plasma will produce a conical wake absent of thermal ions. To maintain charge neutrality a potential develops that repels the thermal electrons producing an electron wake. The size and shape of the wake vary with plasma conditions and a prudent choice for the location of the ER is in the orbital velocity direction hemisphere.

The electronics for the magnetometer and data processing system, PDS interface and power converters are located in the main body of the spacecraft. **It is necessary that the cabling from the electronics to the sensors be provided by the spacecraft contractor per the S/C-MAG ICD (MAG14).**

4.1.2.2 Field-of-View Requirements. There are no special viewing requirements for the magnetic sensors.

Requirements for the ER instrument's FOV are as follows;

(1) **ER Detector FOV must include nadir (MAG15).**

(2) **ER Detector FOV should avoid spacecraft surfaces (MAG16).**

(3) **ER Detector FOV should minimize distortion of trajectories of electrons (MAG17).**

(4) **ER Detector FOV should be near the nominal direction of the interplanetary magnetic field, 122 degrees (solar ecliptic coordinates) from the sun ward line in the ecliptic plane (MAG18).**

(5) **ER Detector FOV should be known to 25 mrad (8 mrad goal) (MAG19).**

The primary science requirement for the ER detector is to measure the incoming and reflected solar wind electrons due to magnetic field increases near Mars. Weak localized Martian surface magnetic fields, will result in reflected electrons at pitch angles near 90 deg. To assure that the ER is always capable of detecting weak surface magnetic fields, the ER FOV must include nadir. The FOV must also avoid spacecraft surfaces to eliminate distortion of electron trajectories measured by the detector. The detector orientation should also minimize any surfaces passing through its FOV. In addition to the measurement of the reflected electron component, the science would be enhanced by a complete measurement of the 2-dimensional electron distribution function. This is accomplished when the ER FOV includes the magnetic field. To maximize the amount of time that this measurement is made, the FOV should include, or be near, the nominal interplanetary magnetic field (IMF) direction of 122 degrees (solar ecliptic coordinates) from the sunward line, in the ecliptic plane. Inclusion of both the nadir and the IMF nominal direction can be accomplished with an ER FOV plane normal to the spacecraft orbital velocity direction

4.1.2.3 Alignment.

Magnetometer Sensors

The triaxial sensor assemblies should be mounted with their reference axes parallel to the S/C principal axes (goal). Note that it is assumed that S/C attitude and maneuver axes are defined by this coordinate system.

Electron Reflector

Detector alignment (or FOV) should be known to 0.5 degrees (goal).

4.1.3 Mars Orbiter Camera (MOC)

4.1.3.1 Position on Spacecraft.

See Section 4.3.3.3 Fields of View

4.1.3.2 Alignment and Relationship to Other Instruments. Alignment between the three optical axes of the MOC optical sub-assemblies should be known to an accuracy of better than one picture element within the wide angle sub-assembly (0.7 mrad), and they must be oriented parallel to the spacecraft nadir vector (+Z) to an accuracy of better than 2.0 mrad (goal). MOC contains CCD line arrays, and these should be oriented parallel to the y-axis to better than 20.0 mrad (goal). The MOC and other instruments on board the spacecraft, in particular the TES and MOLA should be bore-sighted to a precision of better than 2.0 mrad, with knowledge of the alignment to better than 0.5 mrad (goal).

4.1.3.3 Fields of View. **The MOC requires two unobstructed nadir views from the spacecraft to the surface of Mars. All fields-of-view are centered on the nadir axis (+Z) (MOC4). The wide angle assembly has a ~140º FOV in the cross-track (±Y) direction and must have an unobstructed FOV (MOC5)** (to permit observations of both limbs from nominal altitude). The along-track (±X) direction FOV of the wide angle assembly is ~3°. The stray light FOV for the wide angle assembly is ~156.5° cross-track and ~5° along-track. The narrow angle optics has a ~0.44° FOV (both along- and cross-track) and a ~68° stray light FOV (along- and cross-track). In both assemblies, baffling will suppress stray radiation scattered into the focal planes, provided the stray light FOVs are maintained. (Note the precise FOVs are specified in the MOC ICD.)

4.1.4 Deleted

4.1.5 Mars Orbiter Laser Altimeter (MOLA)

The MOLA shall be positioned such that it is aligned with the +z axis with an unobstructed field of view (MOLA3). The instrument mounting should be adjusted at spacecraft integration so that the boresight as determined from an alignment cube attached to the instrument, is within 0.5 mrad of the spacecraft reference axis (goal). The instrument requires an unrestricted field of view equal to a cone of ~10 degrees, truncated at the telescope rim. (Note: the precise FOV are specified in the MOLA ICD.) The investigation team desires co-alignment with the MOC field of view to within 2 mrad.

4.1.6 Radio Science (RS)

Spacecraft hardware for these investigations consists of the tele-communications subsystem (TCS) and USO frequency reference. This hardware is to be supplied and integrated by the Mars Global Surveyor Project. It is a goal that the USO be located in a highly stable thermal environment. (See item 4.2.6 below.)

4.1.7 Thermal Emission Spectrometer (TES)

4.1.7.1 **The TES instrument must be located on the spacecraft to have an unobstructed view in the orbital plane from nadir to space in a minimum of one direction (TES8)** and a view to at least the limb in the opposite direction (goal). The space-view line of sight must be ~15° above the assumed top of the atmosphere (70° from nadir), with a ~10.75° half-angle cone about the line of sight that is free of all obstructions. These angles are measured from the TES aperture. The mirror used to view space is the same mirror used to provide image motion compensation, and is required to scan the fields of view along track, scanning in the X-Z plane with views to the fore (goal) and aft limbs. Stray-energy requirements are for an unobstructed view for ~10° beyond the TES IFOV, resulting in a stray energy cone with a half angle of 10.75°, as measured from the TES aperture. (Note: the precise FOVs are specified in the TES ICD.)

This viewing geometry enables the pointing mirror to provide observations for the full characterization of the surface and atmospheric emission and scattering properties. Limb scans may be the most appropriate measurements for determining the atmospheric properties, which must be removed in order to determine the surface spectrum. Because these cannot be made directly over the groundtrack due to planetary rotation, interpolation or extrapolation will be required to assess the properties of the atmosphere through which the surface spectrum is observed. If both limbs can be viewed, then observations on both sides of the nadir will be available and will be used to interpolate to determine the atmospheric properties over the ground-track.

Fore and aft views will allow much more complete phase angle coverage in the polar regions. These observations will greatly improve the ability to determine the catering properties of the surface frosts, which are crucial to the determination of polar energy balance. Fore and aft views would also allow full exploitation of the two-dimensional mosaicing strategy described in Section 5.1.7.2.1.3.

It is desired that direct sunlight does not strike the entrance aperture of the TES instrument. Because the instrument will be completely covered by a thermal blanket, the major thermal flux will be through the viewing port. Therefore, changes in input flux at the aperture will strongly influence the internal instrument temperature and affect the zero-level instrument calibration. It may be desired that the TES instrument be in thermal contact with the spacecraft to minimize internal temperature changes due to changes in the external heat load.

4.1.7.2 Alignment and Relationship to Other Instruments. Alignment of the nadir-view instrument line of sight to +0.5 mrad with respect to the +Z spacecraft reference axis is desired. In addition, it is desired that the TES scan plane (the X-Z plane) be aligned to the spacecraft X-Z plane to within 0.5 mrad. It is desired that the nadir view of the TES be boresighted to the MOC, nadir view to within ±1.0 mrad. Alignment with the MOC will permit the contents of the TES IFOV to be viewed at very high resolution, providing a direct measure of the spatial extent and distribution of the physical and compositional components.

4.1.7.3 Field-of-View Requirements. The TES has six sensitive fields of view, three (3) across track and two (2) downtrack rows in each of the spectrometer, solar reflectance, and bolometric radiance instrument subsections. Each detector has an 8.3 x 8.3 mrad field of view. An unobstructed view to space beyond either the fore or aft limb and a view to the opposite limb are desired.

Stray radiation requirements are for no spacecraft or payload element to be within 10° of the TES field of view (~10.75° half angle from the line of sight) as measured from the TES aperture. Note: the precise FOVs are specified in the TES ICD.

No external calibration targets are required.

4.1.8 Interdisciplinary Science (IDS)

4.1.8.1 Ingersoll. MOC should have unobstructed limb to limb views transverse to the direction of spacecraft travel. This goal allows MOC to view the same region on two successive orbits and thereby determine the motion of clouds over the 2-hour period. The ability of TES to scan both fore and aft is also valuable for polar radiation studies.

4.1.8.1 Haberle. It would be helpful for TES to view the limb in both along orbit directions to maximize phase angle coverage.

4.2 ENVIRONMENTAL REQUIREMENTS

4.2.1 Deleted

4.2.2 Magnetometer (MAG)

4.2.2.1 Conducted and Radiated Emissions. The basic operation of the fluxgate magnetometer depends upon essentially a fundamental drive frequency and its even harmonics, whose amplitude and phase are a measure of the external field and its direction, respectively. Thus, it is desirable to avoid having the spacecraft generate any signals which are harmonically related to the following drive frequency: 16 KHz±200 Hz. The instrument is particularly sensitive to conducted and radiated interference at the second harmonic of this frequency, 32 KHz±200 Hz.

In order to guarantee that the spacecraft field is well approximated by a dipole, it is necessary that the residual spacecraft field be reduced to 3 nT or less at the position of the outboard sensor. To achieve this level, it will be necessary to implement a magnetics control program to restrict the sources of spacecraft generated magnetic fields.

The preceding discussion has assumed that the sources of magnetic field interference are concentrated in the main spacecraft body. The presence of a large, rotating solar array would pose a significant problem since the basic assumptions for the dual magnetometer technique are violated. It is thus imperative that the stray field associated with the solar array be minimized to a level no larger than the allowed perturbation level (+0.3 nT).

The ER can be sensitive to high frequency conducted or radiated emissions at frequencies between 10 and 100 MHz. Input wiring to the ER will be filtered to minimize the effects of conducted interference.

4.2.2.2 Thermal Requirements. It is necessary to provide thermal control of the sensor assemblies to maintain them within their optimum operating temperature range (-10 to +50 deg C). This will be accomplished by a design which utilizes a 1 watt (max., 0.5 watt typical) electrical heater. It is desired that this heater be powered by an AC current to avoid introducing stray magnetic fields due to the heater current. The heaters are of minimum effective area construction and could be used with DC power, if necessary. Extreme care has been exercised to realize an isothermal design by distributing the heat source along an extended baseplate. The thickness of the thermal and electrically conductive surfaces has been kept to a minimum; this practically eliminates the harmful effects of thermoelectric currents on the measurements. The basic thermal design is almost identical to that implemented for Voyager, ISPM and GIOTTO magnetic field instruments and used with minor modifications for Mars Global Surveyor. The electronic assemblies mounted on the main body of the spacecraft are capable of operating within specifications from -10 to +50 deg C. The spacecraft is required to provide a maximum of 1 watt (two sensors) of unregulated power at an estimated duty cycle of 30-50% for thermal control of the sensors only.

It is necessary to provide thermal control to the ER to maintain it within its operating range (-10 to +50 deg C). The spacecraft will telemeter the ER temperature and provide heater current. The ER is thermally isolated from the spacecraft.

The electronic assemblies mounted on the main body of the spacecraft are capable of operating within specifications from -10 to +50 deg C. The MAG Electronics is thermally coupled to the spacecraft bus.

4.2.2.3 Magnetics, Particles and Gamma Rays. As discussed previously, it is expected that a magnetics control program will be implemented to reduce the spacecraft field at the outboard sensor location to less than 3 nT in a dipolar configuration. If other sensors are located near the magnetometer sensors, the stray magnetic field produced by these devices at the location of the MAG sensors should not exceed 0.1 nT and exhibit a variation (DC to 10 Hz) greater than 0.05 nT. The magnetometer instrument is not sensitive to the expected charged particle and gamma ray environment for the Mars Global Surveyor mission.

The ER will not be affected by any stray magnetic field at levels acceptable to the magnetometer. MCP performance degradation is not expected with the anticipated low levels of penetrating radiation at Mars. Previous experience has shown that these radiations have no effect on MCP lifetime.

4.2.2.4 Microphonics. The magnetometer experiment itself is not sensitive to microphonic effects. However, mechanical resonances in the spacecraft system could result in spurious signals being present in the magnetic field data. These resonances can in principle be induced by mechanical input from other spacecraft subsystems. **Sufficient damping should be incorporated in the design to eliminate mechanical resonances (MAG20).**

The ER is not sensitive to microphonic effects.

4.2.2.5 Organic Contaminants, Outgassing, Thruster Firing. **Exposure of the ER to organic contaminants either in vacuum tests or during the mission shall be avoided (MAG21)**. The MCPs amplification is degraded by any contaminant exposure. To limit this exposure during testing and during motor firings, the ER will contain a vacuum tight closing mechanism. The cover will include a one-time opening mechanism, thermally activated, together with a thermal motor to temporarily re-close the aperture. The ER should be located outside any motor or thruster plumes and the aperture closing mechanism should be activated during motor firings.

4.2.3 Mars Orbiter Camera (MOC)

4.2.3.1 Conducted and Radiated Emissions. The MOC will meet the EMI requirements specified in JPL document, Mars Global Surveyor Instrument Environmental Design Requirements. The MOC will operate within the emission environment specified in JPL document, Mars Global Surveyor Instrument Environmental Design Requirements.

4.2.3.2 Thermal Requirements. The MOC focal planes will operate at a nominal temperature of -20°C by means of passive thermal control. **The MOC electronics will operate at a nominal temperature of +25°C. When not operating, the MOC will require survival heater power (MOC7).**

4.2.3.3 Magnetics, Particles, and Gamma Rays. The MOC will meet the magnetic and radiation requirements specified in JPL document, Mars Global Surveyor Instrument Environmental Design Requirements.

4.2.3.4 Microphonics. The MOC requires that the total magnitude of the acceleration input at the instrument feet be below the levels shown in the following table. This is necessary to keep the variation of pixel position from nominal to less than 2%:

Frequency [Hz]	Level [g (peak)]
2	0.26
2-20	-25 dB/decade
20-100	0.014
100-400	-30 dB/decade
400-2000	+80 dB/decade

4.2.4 Deleted

4.2.5 Mars Orbiter Laser Altimeter (MOLA)

The environmental requirements of the MOLA are contained in the MOLA ICD.

4.2.5.1 Sufficient thermal control shall be provided by the spacecraft t to ensure that the temperature at the mounting surface of the spacecraft structure is in the range -20 degrees C to +30 degrees C under all orbital operating conditions. During cruise/transition orbit the thermal control should hold the temperature at the mounting surface in the range -30 to +40°C. (Note: see MOLA ICD)

4.2.6 Radio Science (RS)

The USO is highly sensitive to variations in the ambient temperature and magnetic field. Under normal operating conditions, the temperature of the USO should remain between 20° and 30°C, and the magnitude of the rate of change of temperature should not exceed 1°C per orbit at the USO (goal). The maximum rate of temperature change at the USO shall not exceed 3°C per hour (see ICD). The USO should not be subjected to stray magnetic fields that vary at a rate exceeding TBD.

The USO should be turned on after launch when the spacecraft assumes the nominal cruise configuration; subsequently, the USO should remain on throughout the entire mission (goal). **Once the USO is turned on, it shall not be turned off, because it takes 3 months to stabilize (RS6)**.

More detailed environmental requirements are specified in the Spacecraft Bus/Ultra Stable Oscillator Unique Interface Control Document.

4.2.6.1 Warm-up Time. The following goals are exempt from any transient effects that occur during warm-up following a period in which the relevant equipment has been turned off. However, spacecraft equipment should be operated in such a way that stable performance is achieved throughout all Radio Science experiments. In particular, it is likely that some components of the TCS will be turned off for purposes of power management during occultations of the spacecraft by Mars as viewed from Earth. When this is the case, the TCS should be reconfigured for Radio Science experiments at a time that yields stable operation prior to emersion, taking into account all warm-up requirements of the relevant equipment. For example, preliminary tests of the TWT microwave amplifier indicate that the required warm-up time may be as much as 120 seconds depending on power available.

4.2.6.2 Capability to Transmit. It is a goal that the spacecraft transmit a nominal X-band signal whenever the spacecraft is 'visible' from Earth during DSN station passes allocated to the Mars Global Surveyor Mission including those associated with gravity campaigns (see Sections 3.2.6 and 5.6.1 for specific tracking requirements).

4.2.6.3 Amplitude Stability. When configured for radio occultation experiments (see Sections 5.1.6 and 5.3.6), the total power input to the spacecraft HGA should vary by less than 0.1 dB (3a) over any 300-second interval (goal).

4.2.6.4 Frequency and Phase Stability. The USO on board the spacecraft should satisfy the following goals for frequency stability and phase noise spectral density:

Integration Times, Sec.	Square Root of Allan Variance
0. 1	5*10-12
1.	1*10-12
10.	4*10-13
100.	4*10-13
1000.	4*10-13

Frequency offset, Hz	Phase Noise Spectral Density (Multiplied to X-Band), dBc/Hz
1.	-49.
10.	-74.
100.	-84.
1000.	-89.
10000 .	-89.

When the downlink signal from the spacecraft is referenced to the USO, the emitted carrier should have a frequency stability, as characterized by the square root of Allan variance, and a phase stability, as characterized by the phase noise spectral density, that are degraded by no more than 2070 and 1 dB, respectively, relative to the expected performance of the USO (as characterized by the numbers given above); this refers to the effects due to all relevant telecommunications equipment (e.g., the spacecraft transponder) (goal).

4.2.6.5 Doppler Noise. When the spacecraft is in the nominal two-way coherent tracking mode under strong signal conditions, the contribution by the spacecraft TCS to Doppler noise should be no more than 0.1 mm/s(3σ) for a 10-second integration time. (goal)

4.2.6.6 Spectral Purity of the Downlink Carrier. When the spacecraft is configured for radio occultation experiments (see Sections 5.1.6 and 5.3.6), the radiation emitted from the HGA shall contain no modulation sidebands or spurious signals greater than -75 dBc within 2000 Hz of the carrier. (goal)

4.2.6.7 Motion of Electrical Phase Center Relative to Center of Mass. The Radio Science experiments are sensitive to motion of the electrical phase center of the HGA relative to the spacecraft center of mass. It is desired that the components of the relative position and velocity along the line-of-sight to Earth be controlled to an accuracy of better than 10 cm and 0.1 mm/s, respectively (both 3σ); here, the relative velocity refers to a 10-second average. If this degree of controls is impossible, then engineering telemetry from the spacecraft should contain sufficient information to reconstruct the line-of-sight components of the relative position and velocity to the stated accuracy. Note that knowledge of the position of the center of mass (including any time variation) within a spacecraft body-fixed coordinate system is necessary as part of this goal. By accomplishing this, the adverse effects of unmodeled relative motion of the HGA can be restricted to an insignificant level in the- atmospheric experiment and to a small though still detectable level in the gravitational experiment.

The impact of a failure to meet this goal depends sensitively on the magnitude and characteristic time scale(s) of the unmodeled HGA motion. The occultation experiments are affected most seriously by motion with a periodicity of about ten seconds; if for example the unmodeled relative motion on this time scale exceeded the goal given above by a factor of ten, then the associated uncertainty in the derived temperature-pressure profiles would probably increase from a few tenths of a percent to a few percent, and HGA motion would become the dominant source of error in the profiles.

The effect of unmodeled HGA motion on the gravity investigation is potentially more serious. The specific consequences of a failure to meet this goal have not been analyzed fully but will be addressed in a sensitivity study to be conducted by the Gravity investigators of the Radio Science Team (TBD).

4.2.6.8 <u>Non-Gravitational Accelerations</u>. If possible, unloading of the spacecraft momentum wheel should not occur during Mars Global Surveyor tracking periods. When unloading must occur during a track, it is desirable that it be done when the spacecraft is not "visible" from Earth, after atmospheric occultation measurements at immersion are complete but before measurements at emersion begin. For orbits where unloading cannot be restricted to Earth occultations, the unloading should be performed as infrequently as possible in events whose duration is as short as possible.

Telemetry from the spacecraft should contain sufficient information such that spacecraft velocity changes associated with momentum unloading can be reconstructed with an accuracy of 0.1 mm/s (goal).

For any period of time between 40 seconds and 24 hours which includes neither momentum-wheel unloading nor spacecraft maneuvers, nongravitational accelerations associated with spacecraft operations (such as those caused by outgassing, propellant leaks, or uncoupled attitude control forces) should integrate to a net velocity change of less than 0.1 mm/s (3σ, per axis goal).

4.2.6.9 <u>Ranging Accuracy</u>. When the spacecraft is in the nominal two-way coherent tracking mode under strong signal conditions, the uncertainty in range measurements introduced by the spacecraft TCS should not exceed 3 meters (3σ goal).

4.2.6.10 <u>Special Spacecraft States</u>.

(1) USO as frequency reference

The spacecraft shall be capable of transmitting with the downlink carrier derived from the USO without regard to the lock status of the uplink receiver(s). The mode shall be selectable by configuration command and shall remain in effect until a reset command is executed (RS7).

(2) Telemetry on/off

The spacecraft shall be capable of removing telemetry from the downlink carrier. The resultant RF output from the spacecraft shall have no data subcarrier or sidebands present (RS8).

(3) Ranging channel on/off

It shall be possible to configure the spacecraft so that the ranging channel and VLBI modulation is off. In this event, the spacecraft downlink ability shall have no ranging sidebands present (RS9).

4.2.7 Thermal Emission Spectrometer (TES)

4.2.7.1 Conducted and Radiated Emissions

4.2.7.2 Thermal Requirements. Pyroelectric detectors will be used in each of the three instrument sections (interferometer, solar reflectance, and bolometric radiance). No cooling of these detector packages beyond the nominal operating instrument electronics temperature is required. The required spacecraft interface temperature for instrument survival is +15° +50°C. The maximum operating temperature in a known state is +15° +40°C. The operational temperature range within specification is +15° +25°C. The variation in input heat load through a single orbit can be up to 8 watts due to variations in the planetary heat load. Thus, TES may desire to be in good thermal contact with the spacecraft bus to provide a larger heat sink for this variable load and minimize changes in the instrument temperature (See TES ICD).

4.2.7.3 Magnetics, Particles, and Gamma Rays. The TES instrument has no particular sensitivity to magnetics, particles, or gamma rays.

4.2.7.4 Microphonics. The TES instrument will be sensitive to microphonics in both the detector and interferometer subsystems. The instrument will be sensitive to microphonics in the 10-120 Hz range. The instrument requires that the microphonic environment on the spacecraft not exceed 0.005 g's in the frequency range from 10 Hz to 120 Hz at the nadir panel position of the instrument.

4.3 POINTING REQUIREMENTS

The spacecraft pointing control and knowledge requirements are as follows:

Control: 10 mrad/axis (3σ)
Knowledge: 3 mrad/axis (3σ)

4.3.1 Deleted

4.3.2 Magnetometer (MAG)

4.3.2.1 Control/Knowledge. Vector data are very important in the interpretation of the magnetic field measurements for the Mars Global Surveyor mission. It is essential that it be possible to transform the vector measurements from the sensor coordinate system to physically meaningful systems. The Magnetic Field Experiment assumes that the spacecraft attitude will be accurately determined by other sensors carried onboard. The relative orientation between the outboard sensor and the spacecraft reference coordinates shall be stable and known to within ±1.0 degree. In addition, the relative orientation between the two triaxial sensor assemblies should be known to within +0.25 degrees (goal). **The alignment between the sensors and the spacecraft reference axes should be known within 25 mrad (MAG22).** The orientation of the ER FOV should be known to within ±0.5° of the spacecraft references (goal).

4.3.2.2 The spacecraft shall be capable of executing calibration maneuvers requiring one axis of rotation in the selected orbit without loss of control or data acquisition capabilities. (MAG23)

4.3.3 Mars Orbiter Camera (MOC)

4.3.3.1 Control/Knowledge. **In order to achieve the most important science objectives, the MOC must point to the nadir within 10 milliradians (2 mrad goal) in pitch, roll, and yaw (MOC7). Engineering telemetry must provide "after the fact" pointing information to at least 3 milliradians (2 mrad goal) in pitch, roll and yaw (MOC8)** to facilitate proper geometric rectification of the MOC images. The goal is equivalent to a pointing accuracy of one-third of a narrow angle field of view, and is consistent with the desired navigation capability of 1 km and 0.3 seconds in along-track position and timing.

Important and useful observations can be made at lower levels of pointing control, but at a commensurate increase in resource utilization (i.e., more images must be expended on each representative area to insure appropriate sampling).

Pointing control that is worse than 10 mrad will greatly compromise MOC's ability to image the Viking Lander sites.

Spacecraft pointing instability rate will degrade the MOC instrument performance if the rate exceeds 0.16 mrad/s for 0.47 milliseconds (ms) [2% of IFOV (0.074 μrad) in one line time (0.47 ms)]. Serious geometric degradation of the image will similarly occur if the rate over the exposure (~1.8 s) exceeds 0.16 mrad/s [78 pixel distortion (2% of image) = 0.29 mrad in 1.8 s]. Spacecraft stability values of 0.01 mrad in 0.5 s or 0.021 mrad in 12.0 s meet this requirement. This stability should be maintained most critically about the pitch and yaw axes.

MOC desires all thruster events, in particular those associated with attitude momentum compensation and orbit sustenance, occur during night-side portions of the orbit. These may occur near the pole.

4.3.3.2 Inertial Reference. The MOC makes no measurements with respect to inertial reference. Rather, the requirement on the knowledge of the location and pointing of the MOC will be in reference to known features on the surface of Mars. It is a goal that spacecraft location and pointing be specified to an accuracy consistent with the following accuracies:

Three Day Prediction	±1.6 km
Reconstruction	±0.8 km

4.3.3.3 Spacecraft Reference Pulse Requirements. **The MOC requires a reference timing pulse every 0.125 seconds (MOC11), which is satisfied by the real-time interrupt signal (RTI) provided by the Payload Data System (PDS).** The MOC desires an absolute time reference broadcast once every ≤100 seconds. These values must be accurate to better than 0.0125 seconds (MOC9).The MOC also desires equator crossing timing information to better than 0.3 seconds accuracy.

4.3.4 Deleted

4.3.5 Mars Orbiter Laser Altimeter (MOLA)

The spacecraft shall control the altimeter reference axis to within 10 mrad in each axis, and shall provide sufficient engineering measurements and telemetry to obtain attitude knowledge to within 3 mrad in each axis (MOLA4). As a goal, 3 mrad control and 1 mrad knowledge in each axis are desired. Instantaneous spacecraft roll rates should not exceed 2 mrad/s (goal).

4.3.6 Radio Science (RS)

Pointing Requirements (these apply only over occultation observation intervals as defined in Section 5.3.6).

4.3.6.1 Absolute Pointing Accuracy. The angular deviation of the spacecraft high-gain antenna (HGA) from the direction to Earth will be consistent with link performance requirements.

4.3.6.2 Amplitude Stability. **The unmodeled contributions to the received power of the downlink carrier shall not vary by more than 0.1 dB over any 50 second interval due to any spacecraft effects (RS10).** Included are variations caused by the spacecraft telecommunications subsystem and spacecraft antenna pointing.

4.3.6.3 Modeling. Some modeling of HGA pointing may be necessary. If modeling by the Radio Science Team is necessary to meet the amplitude stability requirement, necessary engineering telemetry should be provided at high enough frequency and with sufficient resolution. Any additional required information about the spacecraft shall be made available by the spacecraft contractor to the Radio Science Team.

4.3.7 Thermal Emission Spectrometer (TES)

4.3.7.1 Control/Knowledge. The pointing control and knowledge requirements can be divided into three phases: cruise/approach, transition orbit, and mapping orbit.

During the transition orbit period it is desired to obtain observations of the moons Phobos and Demos. The angular sizes of Phobos and Demos are 1 and 0.25 mrad respectively. Because they are smaller than a TES IFOV, the pointing goals are determined by the TES IFOV, and are to point and maintain the satellite within the 3 x 2 array of TES detectors. Thus the pointing control must be ±4.1 mrad along the X and Y axes. This goal includes both knowledge of the spacecraft position and orientation, and knowledge of the satellite ephemerides. The spacecraft motion about all 3 axes must be less than 1 mrad/s in order to maintain the satellite within a field of view during each 2 s spectral observation.

Observations of the Martian surface and atmosphere are also desired during the transition orbit. The navigation goals for these observations are for nadir viewing of the planet with a pointing control of 16 mrad and pointing knowledge of 8 mrad and a spacecraft stability of 1.0 mrad/s about the X and Y axes and 2.0 mrad/s about the Z axis.

The final observing phase will be during the mapping orbit. **During this phase, surface and atmospheric observations will require a pointing control of ±10 mrad about all axes (see TES3). Spacecraft stability requirements are for a minimum of 1.0 mrad/s about the X and Y axes and 2.0 mrad/s about the Z axis (TES9).** Prediction of the spacecraft ephemeris will be required to within 25 km along track for the initiation of orbit sequence start (see TES4). Updates of this position to within 10 km immediately prior to data acquisition are highly desirable. Pointing knowledge of ±3 mrad in pitch, roll, and yaw is required for surface feature identification and global map reconstruction.

In order to view the center of the polar regions it will be highly desired to maneuver the spacecraft at regular (~5 day) intervals to view the central regions of the north and south polar caps. Without this maneuver, the center of the polar caps will not be viewable. Targeting goals are the same as for normal nadir viewing.

4.3.7.2 Inertial Reference. The inertial reference requirements must be consistent with the pointing requirements stated in Section 4.3.7.1.

4.3.7.3 Spacecraft Reference Pulse Requirements. The spacecraft reference pulse requirements are for a minimum of one night-side equator crossing command per orbit. It is desired that this command be accurate to within +5 km downtrack position. The command will be used to initiate the orbit observing sequence.

4.3.8 Interdisciplinary Science (IDS)

4.3.8.1 Arvidson. None.

4.3.8.2 Carr. None.

4.3.8.3 Ingersoll. None.

4.3.8.4 Jakosky. None.

4.3.8.5 Haberle. None.

5. MISSION OPERATIONS

The Mars Global Surveyor investigation science objectives require a continuous set of observations throughout the mission, rather than the periods of high activity traditional to planetary encounter missions. Nevertheless, all data obtained may not be of equal importance and may therefore require changes in instrument operation due to changes in planetary phenomena, data rate, real-time DSN coverage and instrument health. This section describes observation types that distinguish themselves in terms of planetary coverage. Resolution of possible experiment conflicts will occur during development of a science observation profile to be documented in the Spaceflight Operations Plan (642-305). However, experiment data gathering is expected to emphasize autonomous, non-interactive operations with a simple command uplink process.

5.1 SCIENCE OBSERVATIONS

Table 5-1 summarizes cruise/transition orbit observation goals.

5.1.1 Deleted

Table 5-1. Cruise/Transition Orbit Observation Goals

Instrument	Schedule (Cruise)	Duration (Cruise)	Transition Orbit
MAG	Once per month with S/C roll	13 hours	Continuous observations
MOC	Pre and Post MOC Bakeout	14 days	Only if nadir observations
MOLA	None	N/A	None
RS	Occasional	Tracking period	None
TES	MOI - (3 to 24 days)	Few hours per observations	Some observations

5.1.2 Magnetometer (MAG)

5.1.2.1 Cruise/Transition Orbit. Observations of the interplanetary magnetic field during cruise are important to characterize the stray magnetic field generated by the spacecraft and estimate the effective zero level "off- set" of the magnetometers. Spacecraft rolls, about two-axes, provide an accurate determination of effective (including S/C field components) zero levels for the MAG experiment. Since these maneuvers are generally limited by resource constraints, spacecraft flight rules and other considerations, we intend to make additional use of statistical techniques which take advantage of observed properties of the interplanetary magnetic field to estimate effective zero levels. The use of these techniques requires the acquisition of magnetic field data for short periods of time during cruise which typically do not exceed a few days, depending on solar wind conditions.

Observations of the solar wind electron flux during cruise are important for ER instrument checkout and initial calibration. The primary ER measurements at Mars will be of changes in solar wind distribution function caused by planetary magnetic fields. An understanding of detector response in the unperturbed solar wind is essential to the measurements. **The ER shall be turned on if the spacecraft rolls about two axes for MAG calibration (MAG24). The ER experiment should be deployed and activated for data acquisition**

immediately after insertion into the transition orbit (see MAG9). Continuous of data throughout the transition orbit, except during motor firings, is desired to map the Martian bow shock, ionopause and other associated boundaries. Continuous acquisition of data throughout the transition orbit period is desired.

It is desired that the calibrations take place once per month, starting 30 days after launch. The desired calibration scenario is one at launch+30 days, one at launch+150 days, and one at MOI-30 days. These calibrations should be designed as follows:

Rotation about the +Y axis is satisfactory for one component, with a rotation rate of >1 rev/100 minutes.

For the second axis the +Z axis is satisfactory, with a rotation rate of >1 rev/100 minutes.

At least four, 360 degree rotations about each axis are desired.

The 324 bps data rate is strongly preferred.

The ER portion of the instrument is required to be turned on during calibrations, but not necessarily during the maneuvers. Also, depending on the use of thrusters, the ER sensor may want to close its cover if a bipropellant engine is used.

5.1.2.2 Mapping Orbit Operations. **The MAG experiment requires the acquisition of continuous data throughout the mapping phase of the mission (MAG25).** The instrument incorporates sufficient autonomy and does not require commands for operation other than to initiate automatic calibration sequences. Occasional commands may be required that change the data format to optimize the scientific return. The data rate will be adjusted automatically in response to the available spacecraft record data rate. It is desired that the spacecraft perform rolls about the nadir pointed axis at least once per month, to partially determine effective zero levels of the magnetometers and to determine spacecraft charging and wake effects on the ER experiment.

5.1.2.3 Inflight Calibration Requirements. The instrument design incorporates sensitivity, electronic zero level and on-board data processor self-check calibration routines. These will be initiated approximately once per week by ground command when data are being acquired.

The ER instrument design includes onboard test routines to check MCP gain and amplifier thresholds. A self-check of the entire electronics will be made by using an on-board pulser to inject counts directly at the detector anode. These test cycles will be initiated approximately once per week by ground command when data are being acquired.

5.1.3 Mars Orbiter Camera (MOC)

5.1.3.1 Cruise/Transition Orbit/Gravity Calibration Orbit. Moisture bakeout procedures, which include calibration tests, shall be performed for the MOC during early cruise (MOC28). Other than this procedure, the MOC has no requirements to operate during cruise. However, the Project may request MOC observations as outlined in paragraph 3.4.3. Should the project allow observations during the transition orbit, MOC would desire occasional health and status tests. If accurate nadir pointing control is available during the transition orbit, MOC would desire observations along the afternoon terminator from altitudes less than 5,000 km. At 5,000 km altitude, such data would be equivalent to the best Viking Orbiter data, which were acquired over less than 0.1% of the planet. The MOC desires to operate in a nadir-fixed attitude at its real-time transmission rate for a total of 7 days of continuous (24 hr/day) DSN tracking, in order to acquire simultaneous geodetic and gravity observations. This would ideally occur during the Gravity Calibration Orbit, provided the spacecraft was in a stable, nadir-pointing attitude.

5.1.3.2 Mapping Orbit Operations. As noted above in paragraph 2.3.3.2, there are three basic observational modes for the camera (global monitoring, regional targeting, and high-resolution sampling). Each observation will be commanded from within the instrument. Each mode can be conceptually divided into submodes tailored to specific scientific investigations. Such submodes might include, for example:

(1) Global Monitoring:

a) Daily Global Map: full coverage of the planet in one, 24-hr period, resolution limited by available data rate, in one or two colors.

b) Limb Scanning: coverage (up to full, pole-to-pole, dayside coverage) of one or both limbs (12 noon and 4 PM limbs), including visible atmosphere up to 80 km above the apparent horizon, in one or two colors.

(2) Regional Targeting:

a) Cloud Tracking: multiple, repeat coverage of selected latitudes and longitudes for cloud motion studies. Spatial resolutions ≥300 m/pixel; observations from orbit to orbit (117-minute baseline), daily (target areas poleward of 65° are visible on every orbit, although those between 65° and 80° are foreshortened), and longer; in one or two colors.

b) Variable Feature Monitoring: single and multiple coverage over periods ranging to years, to examine variations in surface features as a function of time. Resolution ≥300 m/pixel and up; areas as large as 4 million square pixels (depending on data rate availability) in any combination of along- and cross-track dimensions; in one or two colors.

c) Special Limb Monitoring: repeat coverage of limb scanning over special targets, such as Tharsis Montes (see Global Monitoring, above); in one or two colors.

d) Ground Track Monitoring: central portion of wide-angle image returned at full resolution (better than 300 m/pixel) to aide in orbit determination, mission planning, and data synthesis with other experiments.

e) Stereoscopic Imaging: portions of wide-angle images returned at full resolution (better than 300 m/pixel), imaged at different times (based on optimum stereo convergence angle, approximately 12 days should elapse between observations).

(3) High-Resolution Sampling:

a) Discrete Sampling: preselected (targeted) areas of geologic interest. Resolution of 1.4 m/pixel over areas from 2.8 km x 2.8 km to 2.8 x 25.2 km.

b) Linear Sampling: preselected areas of geologic interest targeted for single swaths of subsampled high-resolution data. Resolution/area coverage variable from 1.4 m (2.8 x 2.8 km) to 11.2 m (2.8 km x 500 km).

(4) Star Imaging

5.1.3.3 Inflight Calibration Requirements. The MOC requires calibration tests to be conducted before and after moisture bakeout during early cruise. The calibration tests consist of a series of star images conducted with the spacecraft spinning about the Y-axis (MOC29).

5.1.4 Deleted

5.1.5 Mars Orbiter Laser Altimeter (MOLA)

5.1.5.1 Mapping Objectives. Continuous operation of the MOLA will provide topographic profiles of the Martian surface with an average spacing between profiles of 9.7 km at the equator after 168 days (3 mapping cycles, or one supercycle) if there is 10±2 km offset between ground tracks of successive 56 day mapping cycles and if the "orbit walk" is 30 km. Subsequent supercycles should be offset in such a way as to provide uniform ground track spacing in a given latitude band.

5.1.5.2 Cruise/Transition Orbit Operations. Brief internal calibration operations may be conducted occasionally during this period to exercise the electronics and check instrument health and status.

5.1.5.3 Mapping Orbit Operations. The MOLA will operate continuously during the mapping mission. **Momentum dumping should not cause the spacecraft to exceed the pointing specifications stated in Section 4.3.5 (MOLA5).**

External calibrations will be conducted using pre-launch information and data to be obtained during the mission. No special command sequences are required for these calibrations; the data to be used from the MOLA are the same as routinely collected. Sources of external calibration information include crossing-arc data from relatively flat surfaces.

Data to be delivered by the Project to the MOLA investigation team consist of its Experiment Data Record (EDR), SPICE kernels, and selected spacecraft engineering data (e.g., momentum dump log). The MOLA team will routinely perform a quick-look health check on the MOLA as soon as possible after data are received.

5.1.6 Radio Science (RS)

5.1.6.1 Cruise Phase. **Data will be required during the cruise phase to test equipment, both on the spacecraft and at the DSN stations, and to test experimental procedures and software for both the atmospheric and gravitational investigations (RS12).** These data will include simulations of radio occultation experiments and periods of radio tracking. (See item 5.1.6.4.)

5.1.6.2 Orbit Insertion Phase. DSN data from tracking of the transitional orbit are desired for use in determining the Mars gravitational field.

5.1.6.3 Mapping Phase. At the beginning of the mapping phase, the Radio Science Team and the Navigation Team will collaborate in the construction of a preliminary model of the gravitational field based on tracking data acquired during the GCO (see Section 3.2.6 and Figure 5-1). The two teams will cooperate closely and will iterate as necessary to ensure that the resulting preliminary field model satisfies the scientific and operational requirements of the MGS Mission. This model will be used in subsequent mission planning and in preliminary reduction of radio occultation data.

The Radio Science investigations require operation of the spacecraft transmitter at specific times during the mapping phase of the mission. Specifically, the spacecraft shall transmit X-band signal whenever the spacecraft is "visible" from Earth during DSN station passes allocated to the Mars Global Surveyor Mission and within the constraints of the spacecraft power system (RS13). The transmissions shall include the interval for radio occultation experiments as defined in Section 5.3.6 (RS14); note that this interval extends into the geometrical occultation of the spacecraft by the surface of Mars at both immersion and emersion so as to assure that neither the uncertainties in predicting the orbit ephemeris nor the warm-up time required for the spacecraft telecommunications equipment preceding emersion will adversely affect the atmospheric radio occultation experiments. During special tracking periods described in Section 3.2.6 and shown in Figure 5-l, continuous DSN coverage of the spacecraft (24 hours per day) has been requested; continuous transmitter operation by the spacecraft shall be available (whenever the spacecraft is 'visible' from Earth) in the same intervals to support these observations if approved.

Occultation Measurements. The radio beam will be used to probe the ionosphere and neutral atmosphere **during all occultations by Mars that occur within the DSN station passes allocated to the Mars Global Surveyor Mission. To maximize the SNR of the carrier, telemetry modulation (both data stream and subcarrier) and ranging shall be turned off (see RS35)**. As emersion from occultation by the atmosphere is too rapid to allow for acquisition of a two-way signal link, **the spacecraft TCS shall be configured such that the onboard USO serves as the frequency reference for the downlink carrier during emersion. For uniformity of data, the same configuration is required at immersion (RS15). The observations shall be done under the following conditions (see RS35):**

(1) **S/C CONFIGURATION:**

(a) **TELEMETRY MODULATION OFF;**

(b) **RANGING AND VLBI CHANNELS OFF;**

(c) **ONBOARD USO AS FREQUENCY REFERENCE for downlink carrier during all occultation events.**

(2) **GROUND CONFIGURATION (also see Section 5.6.1)**

(a) **Recording of closed-loop data; (one way USO Doppler)**

(b) **Recording of open-loop data;**

(c) **Doppler sample rate of 10 samples per second;**

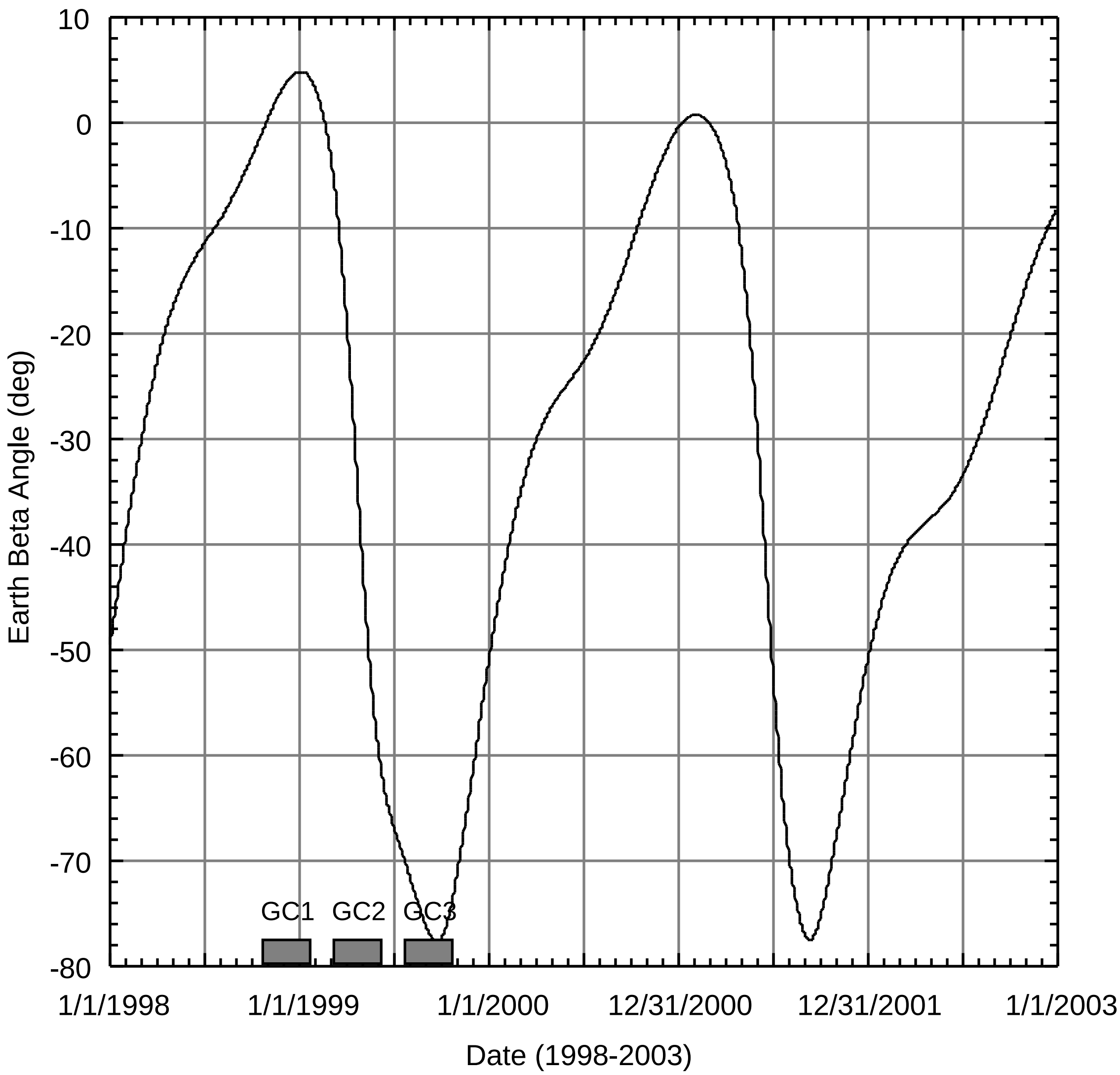


Figure 5-1. Earth Beta Angle

Angle of Earth from mapping orbit plane and Earth latitude from Mars for reference orbit. In implementing the gravity investigation, it is the strong desire of the Radio Science Team to augment the nominal tracking coverage in the mapping phase (one pass with a 34-m antenna every day plus one pass with a 70-m antenna every third day) with three periods of intensive tracking (labeled GC1, 2, and 3). During the gravity calibration orbit (GC0), immediately preceding initiation of the mapping phase, the spacecraft should be placed in an orbit with a repeat cycle of 7-10 days and should be tracked continuously (24 hours per day) over the duration of one repeat cycle. During the mapping phase, the Radio Science Team has no strong preference concerning the choice of repeat cycles, but two gravity campaigns (2 and 3) are strongly desired. Each should consist of continuous tracking of a full repeat cycle at three separate times that span a full mapping cycle. The GCs correspond to complementary observing geometries in that the angle between the orbital plane and the Mars-Earth line is 0° and 75° (the maximum available in the mapping phase), respectively. The GC0 and campaign 2 provide complementary coverage of the north and south poles, respectively, as can be seen from the variation of Earth latitude. During campaign 3, MGS will be observable continuously from Earth. See Sections 3.2.6 and 5.6.1 for further discussion.

Gravity Field Measurements. The frequency of the downlink carrier is precisely measured to determine the magnitude of the Doppler shift resulting from the interaction of the spacecraft with Mars' gravitational field. **The tracking of the spacecraft in the mapping orbit should be as regular, continuous, and complete as possible using as many different DSN sites as possible (see RS24). The observation shall be done under the following conditions (see RS30):**

(1) **S/C CONFIGURATION:**

(a) **Two-way coherent tracking mode**

(b) **Ranging Channel ON**

(2) **GROUND CONFIGURATION (also see Section 5.6):**

(a) **Recording of closed-loop data;**

(b) **Doppler sample rate of l sample per 10 seconds**

(c) **Recording of ranging data at a rate of one sample per 10 minutes**

5.1.6.4 Inflight Calibration Requirements. Tracking system calibrations. Radio metric data during cruise will be used to assess the data quality, to check the overall system for flexibility, and to prepare for the mapping phase.

Antenna calibrations. Inflight observations of the radiation pattern of the spacecraft HGA are desired for the purpose of calibration. The antenna power pattern should be mapped over the main lobe and the first circular side lobe prior to the acquisition of any radio occultation data. The test should reproduce as closely as practicable the preflight calibration described in Section 6.1.6.

USO tests. It is the desire of the Radio Science Team to monitor the performance of the USO during the cruise phase and the orbit insertion phase (spacecraft configuration permitting). This can be accomplished through periods of one-way tracking lasting about one hour each in which the downlink signal from the spacecraft is referenced to the onboard USO. Tests should be repeated about once per month. Configuration of ground equipment at the DSN is TBD.

DSN Radio Science System tests. **Simulations of atmospheric radio occultation experiments shall be performed to test and calibrate equipment both on the spacecraft and at the DSN. During these tests, the spacecraft and participating DSN station should be in the same configuration as for the actual atmospheric radio occultation experiments (RS16) (see Sections 5.6 and 5.1.6.3). At least two tests shall be performed at each DSCC (RS17);** these can be combined with the USO tests described above.

TCS Stability Tests. **In-flight tests shall be performed prior to acquisition of any occultation data to determine the warm-up time needed to achieve stable operation (as per Section 4.3.6) following a period in which the TCS has been turned off (RS18).**

5.1.7 Thermal Emission Spectrometer (TES)

The overall science objectives of the TES experiment, given in Appendix D, will be addressed with a variety of observation types. These include: (1) nadir pointing observations of the surface and atmosphere collected along the spacecraft groundtrack from 1 to 3 detectors; (2) surface mosaics constructed by observing a particular region forward, nadir, and then aft along the groundtrack; (3) limb observations produced by scanning the pointing mirror to and across the limb; and (4) emission phase functions produced by viewing a particular region at a limited set of emission angles fore and aft.

5.1.7.1 Cruise/Transition Orbit. As described in Sections 3.4.7, it is desirable to calibrate the off-axis response of all TES detectors using observations of Mars during the approach phase. This calibration will be performed when Mars has an angular size of 1.0 to 8.3 mrad, corresponding to an approach distance of 6.5 to 0.8 x 106 km. The 3 x 2 array of detectors, covering a total field angle of 24.9 x 16.6 mrad, will permit Mars to be observed within mrad pointing control requirements of the spacecraft. Several sets of observations of this type will provide a unique opportunity to determine the off-axis response of all detectors. This characterization will particularly enhance the interpretation of the limb and summer polar observations.

The transition orbit offers several possibilities to obtain unique science observations. Based on Viking data, the maximum water vapor abundance for the entire Martian year will occur in the north polar region during the period of the transition orbit; the level will be dropping before the mapping mission begins. It will be important to measure this maximum in order to determine the total seasonal change. In addition, it will be valuable to compare the maximum water abundances to the Viking measurements and to measurements taken the following year by MGS. An approach over the north pole would provide periapsis observations of the north polar region, where high water vapor abundances will exist during the transition orbit season. In addition, observations of water-ice clouds and fogs can be made at times of day different from those available during the mapping orbit, providing a measure of their diurnal variability.

The transition orbit also provides opportunities to observe the moons, Phobos and Demos. Both moons will be observable during the mapping orbit (see Section 5.1.7.2), but the signal-to-noise ratio (SNR) will be marginal for Demos during that period. During the transition orbit, however, long integration times can be obtained. These observations will require accurate spacecraft and satellite ephemerides, with a combined pointing uncertainty of +4.1 mrad. Integration on Demos over the 2 hours around periapsis will provide SNRs of approximately 80, 360, and 910 at 7, 10, and 20 µm respectively. No spacecraft maneuvers are required during this integration period.

Finally, observations obtained during the transition orbit will provide a means for studying the instrument performance in response to the actual spacecraft environment and for exercising the command and data processing software and personnel prior to the beginning of the mapping orbit. Preliminary science observations during the transition orbit will also allow initial assessment of the major spectral characteristics of the Martian surface materials and set-up of on-board spectral editing table to allow more effective use of the early part of the mapping orbit. This "Shakedown" period will allow optimal use of the mapping orbit.

5.1.7.2 Mapping Orbit Operations. All TES observations during the mapping orbit will be made using the internal commanding of the scan mirror position and motion, spectral selection, and spatial and temporal averaging and editing. These operations will be commanded using table-driven construction of full instrument commands selected from stored table entries. These commands will be generated as described in Section 4.7.7. Table entries will be updated as required to maximize the science return for varying mission operation conditions and data rates, and as experience is gained with instrument operation and data science content. Specific along-track observational mode changes, such as changing from surface mapping to polar observations, will require prediction of the spacecraft along-track orbital position to within 25 km. Updates of this position to within 10 km immediately prior to data acquisition are highly desirable. **Specific observational targeting for the construction of 50 km x 100 km mosaics will require down-track and cross-track prediction of the spacecraft ephemeris to within 25 km and 10 km, respectively (see TES4, TES5).**

Seasons of highest surface temperature have been chosen for surface compositional mapping, and opportunities provided by increased spacecraft data rate have been incorporated. Using this plan it will be possible to map the entire planet at 3 km surface resolution during the course of the MGS mission. In addition, dust storms, polar cap growth and retreat, seasonal pressure variations, and atmospheric phenomena will be observed.

An integrated mission operations plan will be developed to incorporate surface, atmosphere, polar, and satellite observations. The preliminary strategies and rationales for each individual observation type are described below.

5.1.7.2.1 Surface Observations. Three simple observing modes (nadir views, emission phase angle studies, and the construction of single-orbit mosaics) will provide the full set of observations necessary to address all of the proposed surface science investigations.

5.1.7.2.1.1 Nadir Observations. The nominal TES operating mode will provide a nadir oriented view of the planet, utilizing either 3 or 1 of the crosstrack IFOV's. These observations will be assembled as part of the standard data reduction procedure into global maps of surface observations.

5.1.7.2.1.2 Emission Phase Angle Observations. Multiple emission angle observations will provide information on the scattering properties of the surface and atmosphere over regional areas. Because of planetary rotation (0.24 km/s at the equator) it will not be possible to view exactly the same surface point at multiple emission angles on a single orbit in the equatorial region.

However, regional characteristics can be determined and observations from different orbits may be combined to refine surface photometric estimates for particular locations. Individual emission angle sequences will consist of approximately 5 off-nadir views spaced at intervals of Δcos (emission angle)=0.l.

5.1.7.2.1.3 Surface Mosaics. The TES instrument has the capability to construct mosaics up to 50 km wide by 110 km long from a single orbit with little loss of spatial resolution. These observations will permit the study of regional features, such as dune fields, wind streaks, and the polar lanes on a single orbit.

The surface mosaics will be constructed by using the facts that the planet rotates (moves laterally) under the plane of the MGS orbit, and that the TES pointing mirror scans forward and aft along the plane of the orbit. Surface points which are only modestly ahead of the spacecraft in the orbit

plane move transversely several IFOV's before the spacecraft passes overhead. An example of a mosaic pattern produced using this observing mode is shown in Figure 5-2. The TES footprints are rotated somewhat because of the mirror rotation required to look forward or backward, and there is some degree of enlargement due to the increased emission angle.

5.1.7.2.2 Atmospheric Observations. A wide range of atmospheric observations will be accomplished using the TES. These require both limb scans and variable emission angle observations of the surface and atmosphere. The observing strategy and rationale for several different atmospheric objectives is discussed in the following sections.

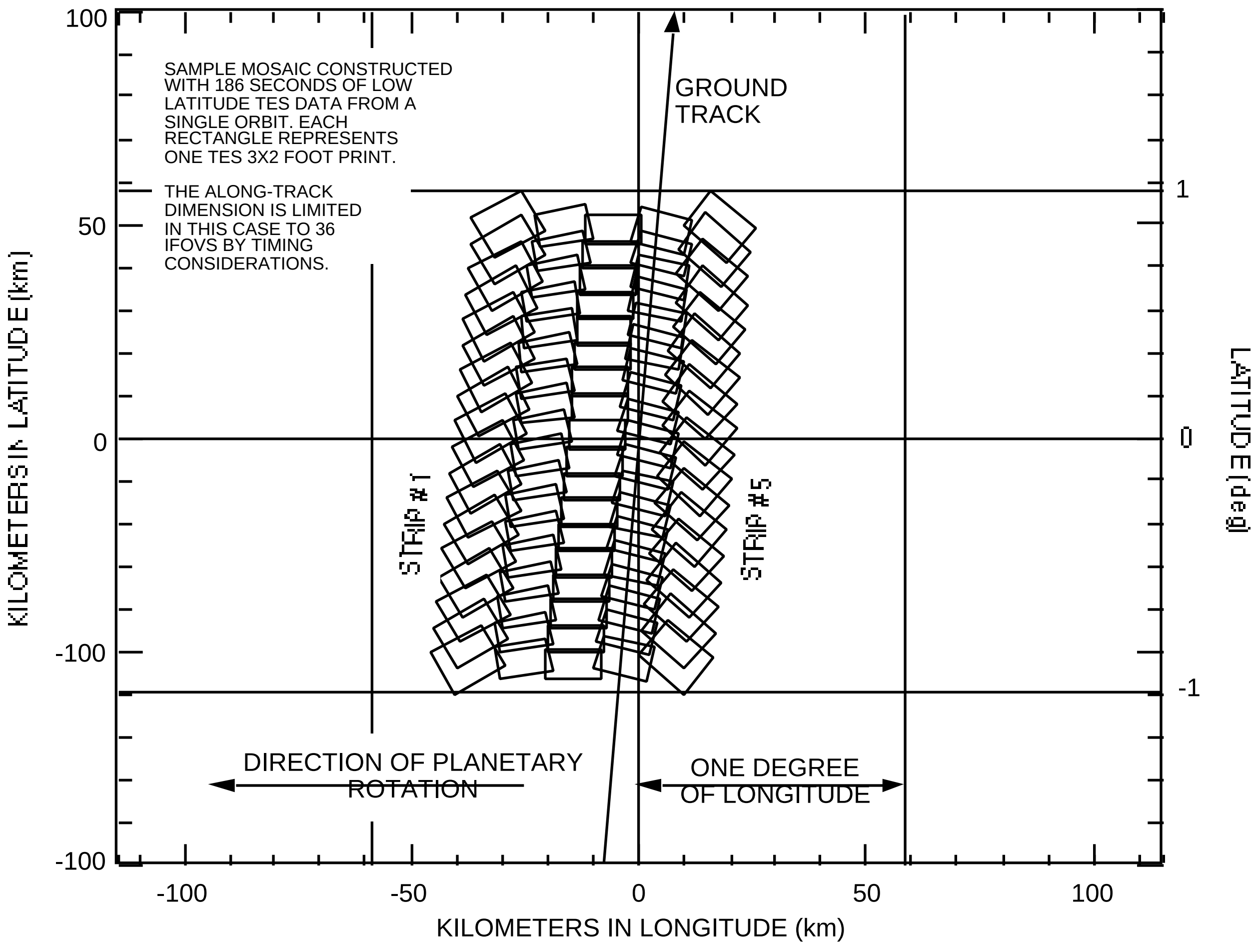


Figure 5-2. TES Mosaic Pattern

The limb scan will consist of overlapping 3x2 IFOV footprints, with the long dimension rotated 67 degrees relative to the horizon due to pointing mirror rotation. The basic scan will cover the atmosphere to 65 km height, and will consist of approximately four viewing positions: the first with the planetary limb filling the bottom pair of IFOV's, and the next elevated by 1/2 IFOV from the previous position in order to improve the vertical resolution; two similarly spaced observations will be positioned above these to slightly overlap the top of the first pair. For dayside observations, the position of the limb will be determined from the signal level in the 1300 cm-l spectral region, which is relatively free of absorption features. The solar reflectance band will be deconvolved to study the vertical distribution of atmospheric opacity. The aerosol composition and distribution will be studied using the spectral data. At night and in the polar regions, the differences in the continuum levels of the spectra in the various IFOV's will be used to estimate the position of the limb.

5.1.7.2.2.1 Atmospheric Aerosol Characterization. The characterization of atmospheric aerosol properties will be very important, both as a means of studying the atmosphere, and to be able to separate the atmospheric from the surface spectral contributions. The spatial and temporal variations of both dust and water-ice require that the atmospheric contribution to the emitted energy be characterized frequently. By viewing fore and aft, the atmospheric properties over the groundtrack can be determined for a particular region. The basic observing strategy will be: (1) forward limb scan (-500 s from nadir crossing); (2) 60 degrees emission angle forward (-168 s from nadir); (3) nadir viewing; (4) 60 degrees emission angle aft (+168 s from nadir); (5) aft limb scan (+500 s from nadir). This atmospheric sequence will be repeated at approximately 10 degree intervals (197 s) along the orbit during daytime mapping. The total time required for an atmospheric sequence is approximately 25 s, or approximately 10 percent of the TES observations.

Simultaneous observations by the radio science experiment and TES are desired to provide a cross calibration between the temperature and atmospheric aerosol retrievals produced by all instruments. Opportunities for this comparison occur twice during the mapping mission: at latitudes of 64 degrees near L_s 220 degrees (the beginning of the dust storm season), and at latitudes of 78 degrees near L_s 360 degrees. In both cases, useful TES observations would be obtained for several days, giving several circuits of the planet. Basic atmospheric limb and emission angle observations will measure conditions at each occultation point and determine the gradients in the region, both across and along the ground track.

5.1.7.2.2.2 Condensates. Throughout the period of formation and dissipation of the north polar hood (L_s 180 degrees to 30 degrees), atmospheric sequences will be performed every 10 degrees of latitude on 13 consecutive orbits to give full longitudinal coverage over the polar hood. This series will be repeated approximately every 10-20 days. Additional emission angle observations will be included at specific points. One observation will be placed to include the point whose limb scans lie closest to the sun/anti-sun line, to obtain possible particle size information from the phase function in the solar reflectance band. Nadir monitoring for water-ice cloud occurrence in the polar regions will also be accomplished. Spectral editing will be performed to optimize the returned data content for water-ice spectral features.

Water-vapor and ozone mapping will be accomplished using the atmospheric sequences at 5-10 degrees latitude intervals along the track every 5-10 days.

The diurnal and seasonal behavior of hazes and clouds having lateral scales of several hundred km will be monitored on time scales of 10 degrees Ls using nadir, limb, and emission angle studies at 1.5 air-masses. Day and night observations will be used to study their diurnal behavior and dissipation. A limb sequence (-500 s from nadir), emission angle observations at 39 degrees (~-87 s from nadir), followed by nadir views and a similar outgoing sequence, will be repeated ever 10-20 days. The forward- and aft-looking observations will provide two parallel sections of the surface, which will be used to study possible wave patterns. Low-lying condensate hazes have been observed within topographically low areas. Because they dissipate shortly after dawn, the TES can only observe these in early morning. Emission angle studies will provide information on the opacity and vertical distribution of these fogs. An important objective of transition orbit observations will be to observe the fogs at times of day other than these available during the mapping mission.

5.1.7.2.2.3 Pressure Mapping. The pressure retrieval method will work best under high surface temperature conditions. A small network of relatively smooth, low latitude sites, well distributed in longitude, will be selected, along with an equal number of high latitude sites for which pressure determinations may not be possible all year. At each opportunity to view a site, a minimum of two short (~-30 s) observations will be obtained, positioned to overlap similar strips on subsequent orbits. This pattern will be repeated for as long as the central strip is accessible; i.e. at three day intervals for up to 5 times. Such observations will be conducted throughout the mission.

5.1.7.2.2.4 Dust Storms. Certain regions, such as Hellespontus, Claritas Fossae, and the boundary of the retreating south polar cap, appear to favor the production of localized dust storms. The horizontal scale of such storms is up to several hundred kilometers, with heights of 10 km or less. The favored areas will be monitored at the appropriate seasons, from both day and night passes, to observe possible diurnal changes in convective activity that may affect the onset and vigor of these storms. An observational sequence to monitor these storms will consist of a series of forward limb scans, fore and aft emission angle observations, and backward limb scans. This sequence will provide coverage over an area 500 km long and 240 km wide at low latitudes with cross-track sections spaced 80 km apart, and a down-track resolution of approximately 10 km.

Global storms will be monitored using a network of fixed locations, including the pressure mapping sites and the summits of the major volcanoes, together with an extended region of uniform characteristics that can be observed on at least two ground tracks per day. These observations will permit the longitudinal and secular changes in atmospheric dust load to be distinguished. The observational sequence will consist of a series of limb and emission angle views of the selected targets, on both day and night passes.

5.1.7.2.2.5 Dynamics. Large-scale baroclinic systems were observed about every three days at mid/high latitudes in northern fall (L_s 200 degrees 250 degrees) during the Viking mission. The TES will have several passes per day, (both in the morning and in the afternoon) over such systems from which much can be learned about their structure and evolution.

The basic observations will consist of a limb and emission angle sequence every 5 degrees between 50 degrees and 70 degrees latitude, with nadir viewing in between. Some spatial averaging should be possible. This sequence will be conducted for periods of one or two weeks every four weeks during fall and winter seasons in each hemisphere.

Circulation patterns in the polar regions can be studied in detail because of the overlap between orbit tracks every 2 hours. The crossover points can therefore be monitored for temporal changes. For 20 orbits every 10 to 20 days, a series of limb and emission angle observations will be conducted at each orbit crossover point for latitudes greater than 80 degrees. Nadir viewing, with spatial averaging, will be performed between these points.

In areas of substantial and/or abrupt changes in topographic relief, such as the slopes of the Tharsis volcanoes or the edges of Coprates Chasma, a significant vertical wind shear (thermal wind) may be present. The presence of these winds can be determined directly from the TES data, again using the combination limb and emission angle observations to probe the vertical temperature structure. Surface targets will be viewed using limb scans every 5 degrees of latitude, with nadir viewing between at intervals of 10 to 20 days.

5.1.7.2.3 Polar Observations. A range of polar observations will be made using the TES. These will be accomplished primarily using nadir and limb observations similar to those used for other surface and atmospheric measurements. However, in order to view the center of the polar regions it will be highly desired to maneuver the spacecraft so that the TES instrument can view the rotational pole of Mars at five day intervals. Without this maneuver, the center of the polar caps will not be viewable. The rationale and strategy for polar observations are discussed in the following sections.

Polar Energy Balance. This study requires phase function observations, particularly in the TES albedo channel when the polar ices are sunlit. TES emission angle scans will be obtained at spacings of approximately one/week intervals at different latitudes over homogeneous areas.

Super Cold Regions. These measurements require good signal-to-noise ratio spectra at full resolution of areas as cold as 128 K. The only predictable areas are the circum-polar "cold-cones"; the regions poleward of 85° latitude where the brightness temperature drops about 1 K per degree latitude. Observations will be made to look for high altitude C02 clouds, and to determine the thermal time-constant for the formation of super-cold areas. Frequent nadir tracks above 80° latitude, with emission angle scans across the rotational pole at approximately 5 day intervals, will be made through the mid-winter season. These observations would require a spacecraft maneuver.

Occurrence of Clatherate. Measurements will be made of homogenous, cloud-free regions to determine the surface kinetic temperature of the frost.

These measurements will be tracked through time to observe the possible occurrence of a temperature plateau near 142 K, indicative of CO_2-H_2O clatherate.

Nucleation Centers and the Composition of the Polar Hood. The TES spectral observations will be examined at the times and locations of the initial formation of polar clouds to determine the composition and abundance of dust nucleation centers. These observations will be combined with atmospheric temperature measurements obtained by TES to determine the H_2O abundance and polar hood composition. This study will require high SNR spectral observations, obtained using spatial integration, and multiple emission angle observations to separate the surface and atmospheric signal.

Annual Cycle of Dust in the Polar Frosts. An estimate will be made of the atmospheric dust content in air parcels that could condense onto the polar caps. Observations will be made of the frost albedo and atmospheric dust content during cap sublimation, and the albedo of the cap at the end of the sublimation period, to study the amount of dust removed from the cap. This study will require atmospheric observations at high latitudes in the fall, and atmospheric opacity measurements from mid- to polar-latitudes during the global dust storm season. Springtime atmospheric opacity and temperature measurements of the dust component in the polar ice, will be used to estimate the amount of dust removed from the cap.

Polar Dark Collars. The albedo, temperature, grain size changes, low-altitude dust transport, and H_2O abundance associated with the low-albedo regions surrounding the retreating polar cap edge will be observed to study the origin of these features. Observations will be acquired across the polar cap edge, concentrating on areas that are homogeneous through the spring season. MOC images to determine the degree of heterogeneity will be incorporated.

5.1.7.2.4 Satellite Observations. During the nominal mapping mission, approximately 910 hours of total time will be available when the TES can observe a point along the opposition side of the orbit of either of the Martian satellites. A single observation would provide SNR's of 140, 620, and 1600 for Phobos, and 17, 73, and 180 for Demos at 7, 10, and 20 µm respectively. Surface spectroscopic investigations of the satellites are therefore possible. Such observations would be scheduled without special MOS support, e.g., satellite ephemeris, using non-interactive commands.

These observations could be made by rotating the TES pointing mirror between 70 degrees and 90 degrees from the nadir. In the mapping orbit this 20 degree angular range is swept out in ~6.6 minutes, thus providing the possibility to remain fixed on the orbit of either moon for this length of time. During this opportunity, the projection of the TES footprint along the orbits of the satellites is 1 degree of arc length, providing a maximum available measurement time per observation of the 1.3 and 5.0 minutes for Phobos and Demos respectively to advance 1 degree along their orbits. At the appropriate MGS-to-moon distances, Phobos will fill 4.5 percent of an IFOV, and Demos will fill 0.2 percent. Co-adding all of the spectra obtained during a single transit provides the SNR's stated above.

5.1.7.3 Inflight Calibration Requirements. Two types of calibration may be performed during flight; off-axis spatial response calibration performed during the cruise/approach phase, and the routine radiometric calibration performed throughout the mission. The off-axis response calibration would be performed using Mars as a point and disk source at 3, 6, 12, and 24 days prior to Mars orbit insertion (see Sections 3.2, 3.4.7, 4.3.7.1 and 5.1.7.1 for additional discussion). This calibration will be performed to map the two-dimensional response of all of the detectors in the flight environment. These data will greatly enhance the analysis of limb and polar observations where detailed knowledge of the field of view characteristics is crucial.

The inflight radiometric calibration will be performed using observations of space (zero level) and an internal blackbody (gain). **The instrument must have an unobstructed view to space with the line of sight at 85 degrees from nadir in at least one direction, with an unobstructed half angle of 10.75 degrees on either side of this line of sight (see TES8).** (All angles are measured from the TES aperture.) These calibration measurements will allow the instrument response function and zero levels to be determined and removed from the measured spectra prior to transmission to the earth. This calibration must be performed internally to permit co-adding of spectra from more than one detector and from more than 1 measurement.

The TES instrument will have an internal blackbody calibration source for the spectrometer and thermal bolometric bands. An internal lamp will be used to provide calibration in the reflectance band. These calibration sources will be viewable by all three instrument sections and provide a complete end-to-end system calibration.

The long-term gain stability of the TES calibration could be monitored using Phobos as a calibration target. These observations would be performed at approximately 2 month intervals, and will require a reorientation of the spacecraft to observe Phobos at full phase. There are no additional inflight calibration goals necessitating spacecraft resources.

5.1.8 Interdisciplinary Science (IDS)

5.1.8.1 Arvidson. To be determined.

5.1.8.2 Carr

5.1.8.2.1 Cruise/Transition Orbit. It is desired that all surface sensing instruments be on and collecting data during the transition orbit. The data acquired during this phase will be useful for assessing the range of detectable variations of surface properties, the location of anomalies, and the degree of correlation of pre-existing geologic maps with various properties of the surface. Such information will be important in establishing the strategy during the mapping orbit, particularly for TES about which decisions regarding spectral versus spatial resolution must be made.

5.1.8.2.2 Mapping Orbit Operations. As previously indicated, the basic need for this investigation is to map the entire surface at the maximum resolution of each of the instruments. Since this cannot be achieved because of downlink constraints a more restrictive set of objectives must be defined. These are

(1) To sample, under clear atmospheric conditions, and with maximum spatial and spectral resolution, every unit identified on the 1:15,000,000 geologic map of Mars and any chemically and mineralogically distinctive units identified during the course of the MGS mission.

(2) Under clear atmospheric conditions, to map the entire rock surface, including those areas at times covered by the seasonal cap, at some intermediate spatial and spectral resolution which is TBD.

(3) To map the topography of the entire surface at the highest spatial and vertical resolution.

In order to achieve (1), the emphasis during the early part of the mission, before onset of dust storms, should be on identifying and sampling those areas where bedrock is most likely exposed at the surface. The investigation has little interest in observations made while the atmosphere is dust laden. After the dust settles out characterization of the surface should continue. The expectation is that, except for local variations, the same areas will have exposed bedrock as before the dust storms, so that high resolution characterization can continue on the basis of pre-dust storm data.

5.1.8.3 Ingersoll. See Section 5.3.9.3.

5.1.8.4 Jakosky

5.1.8.4.1 Cruise/Transition Orbit. No measurements are required during this phase of the mission.

5.1.8.4.2 Mapping Orbit Operations. **This investigation requires that instruments capable of making atmospheric and polar observations (all scientific instruments except the magnetometer) obtain such data in a nearly-continuous manner at all times during the Martian year (IDS4).** For the purposes of this investigation, "nearly-continuous" means that no significant gaps occur in any data set; it is assumed that the Project Science Group (PSG) will determine after detailed discussion whether any instruments will be turned off for a significant time period, and that negotiations with the PI or TL for each instrument will define the appropriate use of various possible operational modes.

During mapping operations, the following observations or analyses are required from the scientific payload. Discussions with the instrument PIs and TLs have ensured that the appropriate observations are indeed planned.

TES - (1) Daytime and nighttime surface temperature information

(2) Albedo and thermal observations of the edge of the seasonal polar cap

(3) Spectral observations suitable for deriving atmospheric water and ozone abundances

(4) Emission phase function observations of selected locations at the surface

(5) Atmospheric aerosol abundances and physical properties

RS - (1) Polar atmospheric temperature profiles

MOC - (1) High-resolution images of the summer polar regions

(2) High-resolution images of selected surface locations

(3) Limb-image estimates of the vertical profiles of atmospheric aerosols

(4) Synoptic images of the spatial distribution of atmospheric aerosols

5.1.8.4.3 Inflight Calibration Requirements. It is assumed that each instrument will be calibrated in an appropriate manner and on an appropriate timescale.

5.1.8.5 Haberle. The following are science requirements placed by this IDS investigation on various experiments:

(1) MOC. Synoptic measurements of the entire globe be obtained once per day during the period of global dust storms, i.e. Ls equal to 200 through 300 degrees. These observations are intended to define the time evolution of local dust storms in both hemispheres and the possible development of a local

southern storm into a global dust storm. During other seasonal dates, global synoptic observations be made at least once per week to define the frequency of occurrence of local dust storms and condensation clouds. Also, during other seasons, synoptic observations of winter mid-latitude regions should be obtained once per day for a week every two months to define the characteristics of baroclinic storm patterns.

(2) TES and MOC. The observations of these instruments will be coordinated to define a global climatology of dust storms and condensation clouds. Such a climatology consists of the three-dimensional frequency of occurrence of these clouds, their composition, the mean particle size, and the optical depth. Such data are to be available for each month of the mission.

5.2 INSTRUMENT PERFORMANCE EVALUATION

Timely access to science/engineering data is required for performance evaluation. The equivalent of a Science Operations Planning Computer, with access to the Project Database, located at JPL could be a useful tool on a representative-shared basis for multi-experiment validation purposes (goal).

5.2.1 Deleted

5.2.2 Magnetometer (MAG)

The performance of both the magnetometer and ER instruments is assessed by monitoring the engineering parameters of the experiment and by certain self consistency checks in the data obtained (see 5.1.2).

All magnetic field experiment source packets delivered by JPL to GSFC will subsequently be processed by the MAG Team to at least Level 1 (Decommutated physical quantities) to verify data integrity and correct instrument operation.

5.2.3 Mars Orbiter Camera (MOC)

The MOC will perform calibration tests using star observations during cruise to evaluate the performance of the camera before and after moisture bakeout. During the mapping phase, the MOC will utilize its science data for instrument performance evaluation. A small lamp near each focal plane will be used for engineering health and status testing.

5.2.4 Deleted

5.2.5 Mars Orbiter Laser Altimeter (MOLA)

5.2.5.1 Purpose. The overall purpose of the instrument performance evaluation activity is to supply a set of information characterizing the altimeter in sufficient detail to permit the scientific end users to interpret its data. The instrument performance evaluation should verify performance in accord with the original specifications at several different times in the instrument's history: (1) prior to shipping from Goddard Space Flight Center to completely characterize the instrument; (2) after spacecraft integration to assure no performance changes; and (3) during the cruise and on-orbit period to verify the correct operation and to characterize features unique to the flight environment.

The post-Mars Orbit Injection (MOI) instrument evaluation consists of an intensive short-term evaluation period followed by a longer period of more occasional evaluation activity. The intensive evaluation should demonstrate that the instrument performs to original specification and reproduces its pre-launch performance. This may require specific short command sequences. The long-term post-MOI evaluation over the entire mapping mission will periodically repeat some of the steps of the short-term intensive activity to confirm continuing adequate performance, and will monitor the instrument's longer term trends.

5.2.5.2 Key Performance Matrix. A key performance matrix will summarize MOLA performance in certain key areas. This matrix allows observations determined at different critical stages of the effort to be compared against each other and against the MOLA's specification. For such a matrix, the row indicates what parameter was measured or characterized, while the column indicates when and where the measurement or characterization was performed. Matrix entries, at an indicated row and column, can be of several different types:

(1) A mean measured value including, when appropriate, standard deviation,

(2) A brief indication of whether or not a given parameter showed a properly functioning system, and

(3) For parameters for which the performance is not being evaluated, the range of values observed.

The Table 5-3 below provides a list of parameters considered for row headings for the key performance matrix. There will be at least four column headings, including: (1) the instrument performance specification, (2) performance and responses to testing prior to shipping, (3) instrument responses to pre-launch testing after spacecraft integration, and (4) the performance and responses when in flight.

Because of the limitations in knowledge and understanding in the intensive evaluation period following MOI, and because of the need to assess various possible sensor longer-term trends over the course of the mission, it is necessary to continue the Mars Orbiter Laser Altimeter assessment and evaluation activity throughout the entire mission although at a lower level than during the initial intensive assessment and evaluation activity. Periodically throughout the mission, an additional set of entries will be made in the key performance matrix to indicate then-current knowledge and level of the instrument's performance.

Table 5-3. List of Parameters for Key Performance Matrix (as row labels).

Performance Requirements
Range
Transmit/Receiver Power Precision
Background Power Precision
Failure-to-Range Frequency
Internal Calibration
Range Bias Accuracy
Range Bias Drift
Science Data
Range
Match Filter Selection
Reflectivity
Background Radiance
Command Response
Standby
Operate
Safe
Special Modes (if any)
Engineering Data
Temperatures
Transmit Power
Voltages
Other Housekeeping

The preceding discussion has treated the key performance matrix as a simple two-dimensional entity. In fact, there are other parameter dependences present; temperature dependence is one example, so that a higher dimensionally may be needed for some of the matrix entries. A best effort will be made to provide entries for this matrix, specifying as fully as possible the temperature and other conditions for each matrix entry.

5.2.5.3 Data Required From Project. Data external to the MOLA required on-orbit about Mars include the spacecraft engineering telemetry and command uplink relevant to MOLA. Additional data required include spacecraft attitude and control information relative to all three axes (MOLA6).

It seems likely and reasonable that the Project will conduct some sort of routine monitoring of housekeeping and health status data for each of the payload instruments. If such monitoring is conducted at JPL, we must receive the data from this activity as well.

5.2.6 Radio Science (RS)

Selected ground monitor data shall be processed, displayed, and monitored in real-time whenever the spacecraft is tracked for purposes of Radio Science calibrations or experiments (see RS23-29). These data are described in Section 5.6.l.2.

In addition, support data concerning spacecraft equipment and operations shall be made available to the Radio Science investigators via the Project Data Base (see RS21). Specific requirements are given in Section 5.6.1.

5.2.7 Thermal Emission Spectrometer (TES)

The inflight instrument health and performance evaluation will consist of two phases. The first will involve the full, detailed checkout of the instrument performance at the beginning of the mission; the second phase will be the routine monitoring of instrument health and performance.

Detailed instrument performance evaluation will require transmission of full, undecimated interferograms and spectra spaced throughout entire orbits. Changes in instrument performance and calibration will be determined with respect to changes in instrument conditions produced by changes in the operating environment throughout the orbit. The instrument must be operated in a mode similar to the nominal mapping mode to reproduce the thermal environment. Frequent observations of space (~1 per 30-60 s) will be performed and the full interferograms and spectra from these observations, as well as the surface and atmospheric observations, will be transmitted. In addition to environmental effects, the stability of the instrument to phase changes in the zero point of the interferogram, and the algorithms to perform phase corrections in the interterogram, must be validated during this period. This checkout will require repeated, full interferograms and spectra acquired over the full range of surface and atmospheric observing conditions.

A high data volume (34,090 bits/interferogram + 1438 bits/spectrum = 35,528 bits total) and rate (1 observation/2 s) are required to perform these performance evaluations. In addition, these observations must be performed continuously throughout the entire orbit to determine the time variations of instrument performance. These requirements result in a data rate of 4992 bps for extended periods.

The second phase of instrument health check will include routine monitoring of the instrument performance throughout the mapping phase of the mission. This evaluation will be performed at the PI institution using standard engineering and housekeeping data transmitted as part of the nominal TES output data stream. Systematic inclusion of full interferograms and derived spectra (approximately 10/orbit), either in the record stream or on a real-time link if available, will provide a full evaluation of the instrument characteristics and stability. The instrument will also be capable of transmitting the command table entries and full memory contents to permit complete validation of the onboard processor activities. In the event of an instrument anomaly, full interferograms and spectra will be transmitted to permit full analysis of the problem.

Instrument performance will be monitored routinely as data are transmitted from the Project Data Base and received at the PI institution, using the Project-supplied workstation, to ensure timely awareness and response to instrument anomalies. **Housekeeping data** will be separated from the data stream and analyzed using a real-time alarm routine to test for out-of-specification conditions. **These data shall be available to the TES team within 24 hours of transmission to the Earth (TES10)**. In addition, a limited set of TES science data including surface, space, and internal reference spectra will be analyzed in real time and automatically compared to previous observations to test for instrument anomalies and performance variations.

5.2.8 Interdisciplinary Science (IDS)

5.2.8.1 Arvidson. Instrument Teams should deliver to the Project Data Base documentation on instrument performance, variations over time, and how such parameters were incorporated in producing reduced data records.

5.3 SEQUENCE DESIGNS

5.3.1 Deleted

5.3.2 Magnetometer (MAG)

There are no specialized sequencing plans for this experiment except for the initial phases and during drift orbit insertion. Internal operating modes will be adapted/modified on a bi-weekly basis depending on the observations.

5.3.3 Mars Orbiter Camera (MOC)

MOC sequence design is divided into two phases: planning (pre-launch to mapping orbit operations) and operations (during mapping orbit operations).

5.3.3.1 Planning: Pre-launch to Mapping Orbit Operations. The principal planning activity for sequence design is identification of targets of scientific importance and entry of these targets into the MOC operational data base. Targets will be identified by position on Mars, and include additional ancillary data as necessary to specify the "E" file information of the SPICE kernel for each observation. For each target, an operational strategy will be developed, including, for example, specification of image size and shape optimized for science coverage, and repeat cycle intervals for WA regional coverage. Representative daily acquisition scenarios will be developed based on model orbits for use in uplink planning exercises, training, and Project MOS planning.

5.3.3.2 Planning: Mapping Orbit Operations. Following initialization of the mapping orbit and longitude grid control, pre-mission targets will be sorted by occurrence along the orbits predicted by the Project Navigation Team. An initial sequence of accessible targets will be created from the list of targets that occur along the predicted orbits and within a tolerance of possible deviations from those orbits. The sequence will then be expanded to meet the available downlink data rate by examination of the orbit predict geography for additional targets of opportunity. Representative, multi-day parameter upload sequences will then be produced, and if required by the Project, concatenated with the Project 28-day command file for uplinking in 3-day segments.

5.3.3.3 Operations: Mapping Orbit Operations. The image sequence developed during the process described above (paragraph 5.3.3.2) will be re-evaluated whenever better orbit predict information is available. Optical navigation, even without feed-back to the Longitude Grid Control, should permit MOC to make a 3- or 6-day prediction that is of substantially better accuracy than that presently planned by the Project. On the basis of tests against this final orbit prediction, one of three activities will be performed for each observation:

(1) Target still accessible (probability ≥25%): execute original parameters (they are already either in the Project queue or have been uplinked to MOC).

(2) Target not accessible at original specification but observation may be salvaged by timing offset: determine sequence parameter modifications and transmit for replacement in Project command queue between execution minus 3 days and execution minus 1 day, or, if sequence already on-board MOC, for uplink to MOC at earliest possible time.

(3) Target not accessible, new target identified: determine full parameter set for new observation and transmit for replacement in Project command queue between execution minus 3 days and execution minus 1 day, or, if sequence already on-board MOC, for uplink to MOC at earliest possible time.

Details of the mission operations are extremely hard to predict at this time owing to the dependence on the actual ground path of the spacecraft. An example mission observational scenario might be as follows:

From initiation of mapping orbit operations through conjunction and until dust storm activity begins, MOC would monitor global conditions (i.e., watching for dust storms and monitoring polar caps) and sample diverse phenomena and locations (the atmosphere will be clearest about the time Mars Global Surveyor gets to Mars, having had a half martian year to settle down).

At the onset of dust storm activity, MOC would enter a storm monitoring phase, where dust storm observations would be made using medium-resolution coverage and selected target would be examined only until such time as the atmospheric opacity reduced the quality of these high-resolution data below a useful threshold. Even after that time, high-resolution samples would be taken occasionally of polar targets, and to view atmospheric features at high resolution (e.g., dust plumes, etc.).

After the dust storms wane, and as the atmosphere clears, a mixture of medium- and high-resolution images would again be acquired. Toward the end of the nominal mission, global observations will be reduced (after the north polar cap has receded) and high-resolution imaging would be acquired almost exclusively, in particular aimed at future U.S. landing site selection.

5.3.4 Deleted

5.3.5 Mars Orbiter Laser Altimeter (MOLA)

There are no special sequences anticipated for the mapping portion of the mission, as the system operates continuously at a single data rate. In the initial intensive evaluation period, it is possible that some command sequences will be designed to perform special testing operations. It would be desirable to plan for a limited amount of altimeter-only data in this period to verify lack of significant interference from other payload instruments.

5.3.6 Radio Science (RS)

Radio Science measurements are made at tracking stations of the DSN. To obtain accurate results, the experiment requires detailed sequences that configure the spacecraft to optimize the down-link signal; ground operations must be designed for reliability. Calibration data are also required from the spacecraft and the DSN station to allow for accurate analysis and interpretation of experimental data.

Spacecraft sequences supporting Radio Science measurements will consist of configuration commands to establish a spacecraft state appropriate for the observations. These commands shall include on/off control of the transponder ranging channel, on/off control of telemetry modulation on the downlink carrier, and selection of tracking modes (see Sections 4.7.6.1 and 4.3.6.9 for command descriptions). It is the intent of the Radio Science Team to record data from all radio occultations of the spacecraft by Mars that occur within the DSN station passes allocated to the Mars Global Surveyor Mission including daily passes with 34-m antennas and real-time passes every third day with 70-m antennas. The configuration sequence encompasses six commands to be repeated during each relevant orbit of the spacecraft: (i) and (ii) telemetry and ranging will be turned off just prior to occultation immersion; (iii) the TCS will be commanded to use the onboard USO exclusively as the frequency reference for the downlink carrier just prior to occultation immersion; (iv) following occultation emersion, the TCS shall be commanded to resume coherent tracking; (v) and (vi) telemetry and ranging will be turned back on. It is intended that **standard sequences** applicable to the entire mission be developed, with only execution times and other orbit-dependent variables to be updated by the Radio Science Team and MOS. **The sequences shall be designed by the Mars Global Surveyor Project in collaboration with the Radio Science Team (RS19). In addition, MOS shall provide the DSN with orbit ephemeris predictions 5 days in advance of the relevant station pass for use in designing command sequences for acquiring data (see RS26)** (see Section 3.3.6 and 4.8.1.4).

The occultation observation interval shall include: (i) the extinction of the signal by the surface of Mars including 20 s of data taken while the spacecraft is geometrically "behind" Mars, (ii) data from the surface to 200 km altitude, (iii) a baseline interval (~100 s) during which the signal from spacecraft to Earth passes above 200 km altitude, and (iv) an appropriate time pad on both ends of the interval just defined to protect against timing uncertainty (RS20). For nearly diametric occultations, the entire radio occultation recording interval will span about 5 minutes. In the grazing occultation geometry, the upper altitude (200 km) may be reduced (value TBD) to accommodate tracking requirements.

The largest possible data volume is needed to gain maximum resolution and separability of gravitational parameters for a large (up to 50 by 50) gravitational field model. **Accordingly, the tracking of the mapping orbit should be as regular, continuous, and complete as possible using as many DSN sites as practical; at least one pass per day with a 34-m antenna is required (see RS14)**. Coherent Doppler tracking data are strongly desired from 70-m ground antennas during real-time passes scheduled every third day.

It is the strong desire of the Radio Science Team to augment the nominal tracking coverage described above with three periods of intensive tracking. The first should occur just prior to initiation of the mapping phase, when the spacecraft should be placed in a gravity calibration orbit (GCO) with a repeat cycle of 7-10 days. The spacecraft should be tracked continuously (24 hours per day) over at least one full repeat cycle, and preferably throughout the biased GCO, the GCO, and the spacecraft checkout period. During the mapping phase, two "gravity campaigns" are desired; in each of these, the spacecraft should be tracked continuously over a full re[eat cycle at three separate times whose spacing is one third of a mapping cycle. Figure 5-1 shows the preferred times for intensive tracking coverage. See Section 3.2.6 for further discussion.

If 24-hour tracking coverage is not available and the nominal tracking schedule makes extensive use of a single ground station, data reduction will become difficult due to effects associated with the wobble of the Earth's pole. At the same time, full resolution global coverage will accumulate relatively slowly under these circumstances due to the near equivalence of the rotation periods of Earth and Mars. For these reasons, it is highly desirable to switch tracking stations regularly. Details of scheduling are presently being studied to minimize station switching while still acquiring fast, even global coverage.

5.3.7 Thermal Emission Spectrometer (TES)

The basic TES measurement consists of a spectrum, an albedo channel measurement, and a thermal bolometric channel measurement, acquired by 1 detector, in each channel every 2 s. An observation consists of the output from the TES internal processor, in which 1 to 6 detectors have been combined for 1 to N measurements. The full data rate for a single observation, assuming all detectors operating and no spectral editing, is 4992 bps. TES sequences will consist of individual measurements closely grouped in space and time with the instrument operating in a constant mode (e.g. nadir viewing or limb observations). Full orbit sets will be constructed of individual sequences.

The TES observational strategy will be implemented using the basic mission plan given in Figure 5-1, and incorporating the detailed surface, atmospheric, polar, and satellite observations described in section 5.1.7. Individual sequences will be constructed from Instrument Command Macros (see Section 4.7.7) that are stored within the instrument and updated as required to optimize the science return. An entire orbit set will be constructed from individual sequences to optimize the available science observations while remaining within the spacecraft resources allocated to the TES investigation. These orbit sequences will be initiated using approximately 1 to 5 commands to the TES instrument each orbit.

The basic sequences will consist of: (l) nadir pointing observations of the surface and atmosphere collected along the spacecraft groundtrack from 1 to 3 IFOV's; (2) surface mosaics constructed by observing a particular region forward, nadir, and then aft along the groundtrack with all 3 IFOV's; (3) limb observations produced by scanning the pointing mirror to and across the limb using all 3 IFOV's; and (4) emission phase functions produced by viewing a particular region at a limited set of emission angles fore and aft using 1 to 3 IFOV's.

5.3.8 Interdisciplinary Science (IDS)

5.3.8.1 Arvidson. The emphasis of this investigation is analysis of representative data samples covering the globe at first, followed by detailed analyses of selected regions. Thus, as discussed in Section 5.1.9, there will be requests for highest spectral resolution TES and MOC data for the areas defined in the Table 5-4. Such requests need to be built into the capabilities associated with sequence designs.

5.3.8.2 Carr. The success of the investigation depends on correlation of data from all the surface instruments as the mission progresses. Most of the data acquisition by TES and the altimeter should be relatively simple, the TES and altimeter building up spatial coverage. The MOC, however, will operate partly in a high data rate burst mode in which data is taken at high spectral and/or spatial resolution. Only a small fraction of the planet will be covered at these resolutions. (The other surface sensing instruments may also have high data rate modes in which they cover only a limited part of the planet). Because only a small part of the planet will be covered in the high data rate modes, the timing of the observations (choice of area covered) will be crucial. The choice should be based at least on (1) a desire to sample all major bedrock units, (2) a desire to concentrate on those areas where bedrock units (as opposed to superficial dust) are best exposed, and (3) a desire to sample anomalies. To make such choices implies timely processing and cross correlation of all surface data so that recognition of 'bedrock units and anomalies' takes place as the mission progresses. Choice also implies scientific interchange takes place as the mission progresses so that the implications of the different data sets can be assessed in time to affect the subsequent conduct of the mission.

Table 5-4. Spectral Resolution Data

Region	Location	Reason for Selection
Chryse Planitia - Oxia Palus - Lunae Planum	15 to 30 deg N 0 to 65 deg W	Transect including variety of bedrock types. Includes Mutch Memorial Station site for ground truth.
Utopia Planitia	15 deg N to 20 deg S 200 to 210 deg W	Amazonian and Hesperian plains to north; Noachin heavily cratered units to south.
Syrtis Major - Isidis	10 to 15 deg N 270 to 310 deg W	Transect from Noachin heavily cratered units to Hesperian and Amazonian Plains.
Arsia Mons - Syria Planum - Sinas Planum	5 to 20 deg S 80 to 130 deg W	Transect from Tharsis Plateau volcano and flows (Arsia Mons) to Amazonian Plains and western segment of Valles Marineris.

5.3.8.3 Ingersoll. Some complexity must be tolerated. First, the data rate is changing during the mission, and each instrument will have to decide how best to adjust to the changes. Second, Mars is changing with the seasons, and different targets (polar caps, clouds, dust storms) are better at different seasons. Third, coordination between instruments is necessary. Simple, low resolution mapping along the ground track is not always the right approach. Intensive study of specific regions at highest possible spectral and/or spatial resolution may be better, but all instruments should try to observe the same regions. Finally, coordination is necessary if all instruments are to observe a dust storm, since a decision must be made to issue non-interactive commands on short (3-day) notice. The solution to all these requirements is proper staffing for sequence design, budgets for travel to Working Group meetings, and willingness by the MGS Project to develop a number of 30-day sequences each of which satisfies a different objective.

5.3.8.4 Jakosky. It is assumed that each instrument will design its internal sequences to provide an appropriate data base, and that discussions within the PSG or between the individual PIs, TLs, and IDSs will allow an appropriate design and selection of sequences.

5.4 DATA TRANSMISSION REQUIREMENTS

Table 5-5 lists the spacecraft record, playback and real-time transmission data and symbol (counting Reed-Solomon code overhead) rates. Table 5-6 gives the experiment data rates for 6 modes of operation consistent with these spacecraft rates. The nominal plan shall be to utilize Science and Engineering-l (S&E-l) 24 hours per day, and S&E-2 for eight hours at least every third day throughout the mission (excepting solar conjunction +TBD days to be determined by Project Study). These data are to be returned with a transmission bit error rate (BER) of 10^{-6}.

5.4.1 Deleted

Table 5-5. Mars Global Surveyor Science Data Rates

	Data rates	Encoded Symbol Rate
Record Rates	3488 bps 6976 bps 13952 bps	4000 sps 8000 sps 16000 sps
Playback Rates (24/4.5 ratio)	18602.67 bps 37205.33 bps 74410.67 bps	21333.33 sps 42666.67 sps 85333.33 sps
Real-Time Rates	34880 bps	40000 sps

Table 5-6a. S&E-I Record-Only Data Modes

Mode ID	L1	L2	L3
S&E-l Rate	3488	6976	13952
MAG/ER	324	648	1296
MOLA	618	618	618
TES	688	1664	1664
MOC	700	2856	9120
S/C	256	256	256
PDS	48	48	48
FRAME FILL			
FRAME HDR	32	64	128

Mode Usage:
- L1 - 4000-sps low-rate record
- L2 - 8000-sps medium-rate record
- L3 - 16000-sps high-rate record

Table 5-6b. Combined Real-time (S&E-2) and Recorded (S&E-l) Data Modes

Mode ID	R1	R2	R3
S&E-l Rate	3488	6976	13952
MAG/ER	324	648	1296
MOLA	618	618	618
MOC	1388	4520	10782
S/C 405	256	256	256
PDS	48	48	48
FRAME FILL	1	1	3
FRAME HDR	32	64	128
S&E-2	34880	34880	34880
TES	4992	4992	4992
MOC2	29260	29260	29260
S/C	256	256	256
PDS	48	48	48
FRAME FILL	4	4	4
FRAME HDR	320	320	320

Downlink Rates (during real-time passes with Reed-Solomon encoding):
R1 - 40,000-sps real-time plus 4000-sps low-rate record
R2 - 40,000-sps real-time plus 8000-sps medium-rate record
R3 - 40,000-sps real-time plus 16000-sps high-rate record

5.4.2 Magnetometer (MAG)

The MAG digital data system, as generally described in Appendix D and including the A/D converter and ER electronics, constitute a "smart" system designed to perform all the required operations on the raw data acquired by the magnetometers. This system will format the source packets to be delivered to the Payload Data System (PDS), monitor experiment status, modes of operation, housekeeping functions, etc. The basic approach is to implement a system such that all data processing operations are carried out under software control and under the supervision of a master executive program, resident in ROM. A set of default parameter tables and vectors are associated with the executive system such that the instrument does not require any commands except for ER high voltage adjustment or upon power-up for proper initialization and data acquisition. The ER must be commanded on for safety reasons. However, a number of table driven routines can be executed to optimize calibration constants, sampling, filtering (averaging), and data compression algorithms, limited reprogramming of source packet format, etc.

The analog information from the magnetometers is sampled at an internal rate of 32 samples/s. This rate has been chosen taking into account a plausible maximum time resolution which may be required to resolve science issues related to the separation of fields of internal or external origin, or associated with the spacecraft itself. The processor will perform a number of optional linear operations on the data:

(1) Data Decimation, which is the selection of a fraction of the available samples for transmission to the ground.

(2) Data averaging, over programmable averaging intervals to implement sampling rates consistent with the rates available from the spacecraft and thus minimize aliasing effects.

(3) Data Compression, which is the implementation of at least one of several differencing algorithms (6-bit) to increase significantly the coding efficiency of the digital information transmitted to the ground.

Digital data from the ER is read out over a serial line by the MAG DPU and stored in RAM. Data is read out each energy step (32 ms) of the electrostatic analyzer with an entire energy sweep taking 1 second. The MAG DPU also controls the operating mode, high voltage, and pitch angle sorting of the ER. The large volume of data generated by the ER cannot be transmitted within the telemetry allocation, thus a primary task of the processor is to reduce the large volume of data to physically meaningful parameters. The primary operations performed by the processor on the ER data are as follows:

(a) Sorting and storing data for slow time (~24 s) readout of average distributions and energy spectra.

(b) Calculation of loss cone and source angles for fast (~1 s) readout. These calculations will include 3 parameter fit that will characterize the atmospheric loss cone angle and statistical error.

(c) Calculation of bulk parameters including density and velocity moments, and determination of spacecraft floating potential.

The MAG DPU will interface with the spacecraft PDS through the Bus Interface Unit (BIU). The DPU will contain two sets of dual "ping-pong" buffers for source packet formatting and access. One set of buffers is required for the magnetometer data while the other set is used for the ER. While separate packets for the ER and magnetometers are being assembled, two packets, one with magnetometer data and one with ER data, are available for collection.

To simplify and standardize the interfaces with the PDS interface circuits, the baseline microprocessor proposed for this instrument is the CMOS 80C86 with a 82C37A DMA controller. A fall-back design will be maintained in case of difficulty with these parts using two NSC800 or 80C85 parts. These devices are either available now or are anticipated to be available in the immediate future as high reliability, radiation tolerant units.

The state of the magnetometer and ER instruments at any moment is provided through housekeeping information contained within the source packet, except for monitoring functions required when the instrument is not powered up, such as sensor and instrument temperatures (MAG26). Implementation of the command subsystem is hardware independent of the microprocessor system to allow commanding even in the event of software hang-ups or transient upsets. This approach depends critically on the final design of the PDS interface and payload command protocols selected for Mars Global Surveyor. Partial reprogramming of the flight software is possible through this interface to optimize the instrument configuration when required.

5.4.2.1 Data Rates and Bit Error Tolerance. The data rate required for the magnetometer experiment is a direct function of the spacecraft (or "record") data rate available at a particular time during the mission. The minimum sample rate for the observations is 4 vector samples per second. This generates an internal rate of 144 bits/s for the outboard magnetometer and approximately 16 bits/s for the inboard magnetometer and ancillary data.

At the higher record rates, the magnetometer experiment is allocated proportionately higher data rates up to a maximum of 320 bits/s corresponding to the 14 kb/s, S&E-l mode. It is assumed that the packet structure will remain constant, independent of the data rate and only the packet collection rate will vary with the spacecraft record rate.

The data required for the ER is also a direct function of the spacecraft data rate. The minimum ER data rate for each 24 seconds and 2 second resolution of loss cone angles at 3 energies is 160 b/s. Higher bit rates of 320 bits/s produce 6 second resolution of average distributions and 1 second resolution of loss cone angles at 6 energies.

The overall maximum acceptable bit error rate to the magnetometer experiment is 10^{-5} (MAG27). This number refers to the total number of packets collected from the spacecraft. Thus the packet header bit error rate should be significantly smaller to avoid a significant loss of complete packets due to header identification errors.

5.4.2.2 Telemetry Modes and Packet Content. There will be three primary types of packets generated by the magnetometer experiment:

1) Magnetometer science packets

2) Electron Reflector science packets

3) Diagnostic engineering and health status packets

Typically the first two packet types will be transmitted alternately. The third packet type will be used for checkout during tests and emergency situations. The MAG science packets will be fixed format. The ER will operate in one of three modes, generating three packet types: 1) Mars orbit insertion (MOI) mode, 2) mapping mode, and 3) calibration mode.

The issue of bit errors in the packet header cannot be addressed by the magnetometer experiment alone. The anticipated packet structure will contain some form of cyclic redundancy code for internal error detection/ correction. However, the correct identification of magnetic field experiment packets must be done by the Mars Global Surveyor data capture facility.

5.4.3 Mars Orbiter Camera (MOC)

5.4.3.1 Data Rates and Bit Error Tolerance. The MOC is capable of matching any downlink data rate available on-board the Mars Global Surveyor spacecraft. It has been assigned the data rate allocations (in bits per second) given in Tables 5-6a and 5-6b. Bit error tolerance for compressed MOC data is 1 part in 10^6 (MOC10). Should the spacecraft telecommunications link be unable to perform the Reed-Solomon encoding, raw MOC data could experience bit errors of 1 part in 10^3 and still make excellent pictures.

5.4.3.2 Telemetry Modes and Packet Content. The MOC internally formats its observations, and uses one PDS packet size for all data return. That packet size is 8,640 bits (540 words).

5.4.4 Deleted

5.4.5 Mars Orbiter Laser Altimeter (MOLA)

The required digital data rate for MOLA, including packet overhead, is constant at 618 bps (MOLA7). A telemetry packet is 8640 bits, consisting of seven two-second data frames and a 1416 bit header, and is generated once every 14 s. Frame format and packet format information is provided in Tables 5-7 and 5-8, respectively.

5.4.6 Radio Science (RS)

A variety of support data will be required by the Radio Science Team concerning spacecraft equipment and operations. **Telemetry from the spacecraft shall either contain or be sufficient for determining the physical state of the spacecraft, the USO operating status non-gravitational forces on the spacecraft and the TCS operating status (RS21).**

1) Physical state of the spacecraft, including mass, center of mass in spacecraft body-fixed coordinates, attitude, pointing direction and boom geometry of the HGA, and the line-of-sight components of the position and velocity of the HGA electrical phase center relative to the spacecraft center of mass (see 4.3.6.7).

2) USO operating status, as characterized by the oven current, the oscillator regulator voltage, the RF output level, the on/off state, and the ambient temperature.

Table 5-7. MOLA Data Frame Format (2 second frame)

Data Collected Every 0.1 second:		
Range to surface (LSBs)		16 bits
Match filter channels triggered		4 bits
Laser transmit pulse energy		8 bits
1st channel receive pulse energy		8 bits
2nd channel receive pulse energy		8 bits
		44 bits
@ 10 Hz x 2 seconds	=	880 bits
Data Collected Every 2 seconds:		
Range to surface (MSBs)		4 bits
Channel backgrounds 4x16		64 bits
Range gate delay		8 bits
Range gate width		8 bits
Range gate tracker status 2x8		16 bits
Receiver threshold settings 4x8		32 bits
Sensor status 3x4		12 bits
Flight computer status		8 bits
		152 bits
Total Frame Size:		1032 bits

Table 5-8. MOLA Packet Format

Word	Data	Length
1-6	Source primary header	48 bits
7-11	Time code words	40 bits
12-177	Engineering frame	1328 bits
178-306	Data frame 1	1032 bits
307-435	Data frame 2	1032 bits
436-564	Data frame 3	1032 bits
565-693	Data frame 4	1032 bits
694-822	Data frame 5	1032 bits
823-951	Data frame 6	1032 bits
952-1080	Data frame 7	1032 bits
		8640

3) Non-gravitational forces on the spacecraft1 as characterized by the time, duration, and magnitude of all thruster firings, as well as the time, duration, and magnitude of each momentum unloading event (see 4.3.6.8).

4) TCS operating status, as characterized by the nominal telemetry data from the TCS.

These data should be delivered electronically to the project Data Base. See Section 5.4.6 for data record requirements.

5.4.7 Thermal Emission Spectrometer (TES)

5.4.7.1 Data Rates and Bit Error Tolerance. The maximum and internal data rates of the TES instrument are given in Table 5-9. A data rate of 4314 bps preserves the full spectral and spatial capability of the TES experiment. Given the data rate constraints on the Mars Global Surveyor mission this full rate will only be acquired during portions of each orbit and the data will be internally buffered for playback to the PDS at constant rates of 688 and 1664 bps (approximate), assuming a factor of 3 data compression, corresponding to the spacecraft playback rates of 4 and >8 kbps. In addition to these rates, rates of up to 4992 bps, corresponding to the full spatial and spectral resolution of the TES instrument with no data compression, could be used if available.

In addition to the 688 and 1664 bps record rates, it is required that TES have the capability to downlink data in a real-time mode (TES11). The output rates from the instrument correspond to the full interferogram plus fill spectrum rates from a single detector. Assuming a double-sided interferogram using a gallium arsenide laser diode fringe counter (821 nm), and 14 bit encoding, the interferogram has an internal data rate of 34,090 bits/2 s or 17,045 bps. Combining these data with the full spectral data at 1438 bits/2 s (719 bps) gives a total real-time downlink rate of 17,764 bps (approximate). **A rate of 4992 bps is required (TES12) during each real-time orbit to return these data to permit** complete, rapid instrument checkout using the raw interferograms for extended time periods and to permit full spectral and spatial mapping.

The TES processor will operate in a wide variety of data collection and processing modes that will allow maximum flexibility in the types and data volume of observations that will be made. A variety of observing modes will be used to access 1 to 3 of the cross-track detectors and time-integrate from a single IFOV up to any number of IFOV's. These observing modes can be used over different parts of the orbit for different mapping sequences. For example, the full sampling rate can be utilized during that portion of orbit when the spacecraft is over the warmest region of the planet, and spectra can be averaged and the sampling rate reduced at night and over the poles in order to increase the spectral SNR. Examples of the nominal, minimum, and maximum (approximate) observing strategies are given in Table 5-10. These demonstrate that the TES nominal mission can be accomplished at a data rate of 15% of the spacecraft data rate. Enhanced observing strategies will be employed during periods of increased downlink data rate.

Table 5-9. TES Data Rates

Full Interferogram:	1 spot = 34,090 bits/2 s = 17,045 bps 3 spots = 102,270 bits/2 s = 51,135 bps
Full Spectra:	1 spot = 1438 bps (Interferometer + Albedo + Bolometric) 3 spots = 4314 bps (I + A + B)
Reduced Spectra (3x)	I spot = 480 bps (I + A + B) 3 spots = 1438 bps (I + A + B)

Engineering housekeeping data will be 40 bits/source packet (8840 bits desired), providing 5 engineering measurements approximately every 60 seconds at the lowest TES playback rate and 5 engineering measurements approximately every 15 seconds at the highest TES playback rate. At these rates the housekeeping data rate will vary from 0.66 bps to 2.6 bps.

Additional science data will consist of: (1) the necessary time identifiers; (2) observing mode verification words; and (3) on-board processing coefficients. These data will require approximately 50 bits per returned spectra, or approximately 20 to 75 bps for the lowest to highest TES data rates.

All data processing within the TES is under software control. The TES will be able to downlink raw interferograms or raw spectra, as well as spatially and/or spectrally edited data. During an initial characterization period (preferably including part of the transition orbit phase), full spectra will be transmitted, with correspondingly lower spatial coverage. As knowledge of the Martian surface spectra improves, spectral editing will be increased, with a corresponding increase in spatial coverage.

In order to maintain a nominal downlink rate of approximately 688 b/s, the TES data processor will perform the following types of on-board processing and editing functions:

(1) Fourier transforms

(2) Digital filtering

(3) Addition/subtraction of a reference spectrum (the blackbody)

(4) Division by a reference spectrum (instrument response function)

(5) Changing reference spectrum upon ground command

(6) Spatial and temporal editing and averaging of spectra

(7) Selection of output data, from raw interferograms to full or edited spectra

(8) Division or multiplication by a Planck function

(9) Data compression

Table 5-10.

Minimum Observing Sequence							
		Surface Observations			Atmospheric Observations		
Region	Degree of Latitude	Seconds	IFOV per Second	Data Vol. $x10^6$ Bits	Monitor	Profile	Overhead
Day-Map	60	1180	3	5.09	4	2	
Day-Monitor	80	1580	1	2.27	8	0	
Polar	80	1580	1/10	0.223	2	2	
Night	140	2760	1/5	0.794	7	0	
Total		7100		8.39			$0.29x10^6$
Average Data Rate			1180 bps + housekeeping + overhead ~ 1225 bps				
Data Compressed (1.8) Rate			~686 bps				

Nominal Observing Sequence							
		Surface Observations			Atmospheric Observations		
Region	Degree of Latitude	Seconds	IFOV per Second	Data Vol. $x10^6$ Bits	Monitor	Profile	Science Overhead
Day-Map	100	1970	3	8.51	6	4	
Day-Monitor	40	790	3	3.41	3	1	
Polar	80	1580	1/2	1.14	2	2	
Night	140	2760	1	3.97	7	0	0.69
Total		7100		17.0			$0.51x10^6$
Average Data Rate			2398 bps + housekeeping + overhead ~ 2470 bps				
Data Compressed (3x) Rate			~1650 bps				

To reduce the wide dynamic range inherent in emitted radiance, spectra will be normalized on board using an approximation to a Planck function generated by a rational function (so that no logarithmic or exponential functions are required). The normalization temperature used for each spectrum will be downlinked so that the measured spectral radiance can be recovered exactly.

To further reduce the downlink data rate requirements, we plan to use the noiseless data compression scheme developed by JPL. Based on studies for strawman payload instruments, substantial compression of interferograms and raw spectra are expected. Separate preprocessing algorithms will be used for interferograms, and raw spectra in order to achieve appropriate work populations. By their nature, interferograms are of almost ideal form for data compression. For greybody spectra with a few strong features, subtraction of a spectrum from its peak radiance is a simple, effective way to invert the population and may be sufficient for preprocessing. Critical parameters used in preprocessing will be redundantly downlinked.

The bit error tolerance for the TES downlink is 10^{-5} (TES13). At this rate approximately 1 in 10 source packets (length 8840 bits) will contain a bit error. The header, time word and packet error control bits of each source packet occupy 104 bits or 1.17% of the source packet. Therefore, fewer than 1 in 1000 source packets may not be fully interpretable. Each source packet will contain approximately 17 full spectra, so that fewer than 1 in 170 spectra (0.6%) will contain a bit error. For spectral data, individual bit errors are generally easily detected and corrected or excluded. In the most extreme case of temporal and spatial averaging (which will only occur over the polar regions), an individual spectrum will contain data that has been averaged for approximately 18 seconds and covers a region of 9 km x 30 km on the ground. For daytime mapping, individual spectra will only cover 3 km x 3 km. Thus, the data gaps produced by the loss of individual measurements will be small and acceptable.

5.4.7.2 Telemetry Modes and Packet Content. Three TES data output rates are proposed, corresponding to two record and playback rates and one real-time rate. The record rates are 688 and 1664 bps corresponding to the nominal and maximum rates given in Section 4.5.7.1, Table 4. The real-time rate is 4992 bps (approximate) for transmission of the full spectral and spatial information content of the TES, and for transmission of a full, undecimated, unbuffered interferogram and a full spectrum for instrument performance checkout, health, and anomaly analysis.

The source packet will conform to the format and maximum allowable size in a transfer frame as specified in the Mars Observer Spacecraft Data Standards (D-1672). Forty (40) bits of the data field will be reserved in each source packet for engineering housekeeping data. The remainder will be utilized for science data. The contents of the data field will vary with instrument function. The contents of this field will be controlled and identified internal to the TES instrument.

5.5 COMMAND REQUIREMENTS

Commanding of the spacecraft and the payload will be through the Ground Data System (GDS) to the spacecraft Command and Data Handling (C&DH) subsystem. There are two major classes of commands sent to the spacecraft C&DH from the GDS: Stored Sequence Commands (SSC) and Real Time Commands (RTC) (see Table 5-11).

Stored Sequence Commands (SSC). SSC are a set of integrated predefined commands stored on-board in the C&DH for execution at a future specified time. The SSC will include both spacecraft bus and payload commands. Spacecraft bus commands are engineering commands to the spacecraft subsystems (including attitude and control).

Payload commands are PDS configuration and operations commands; payload commands; and instrument commands. The C&DH has allocated 1500 words for these commands. (a word = 16-bits + timing information)

These commands are:

(1) generated as 28-day sequences;

(2) uplinked every 3 days;

(3) 16-bit words plus timing information;

(4) either interactive or non-interactive commands;

(5) identified for execution at a specific time;

(6) executed onboard the spacecraft without individual command execution from the ground.

Table 5-11. Nominal Mars Global Surveyor Payload Command Summary

Instrument	SSC 3 Day Load (Single word/ 16-bit words)	RTC Daily Memory Loads (16-bit words)	RTC Daily Single Word Commands (16-bit words)
MAG/ER	2	N/A	N/A
MOC	N/A	~2500/day	<750/day
MOLA	None	None	N/A
RS*	120	N/A	N/A
TES	Infrequent	700/3 days	N/A
PDS	TBS	TBS	TBS

*RS commands are spacecraft commands and are not included in the payload command total.

Real Time Commands (RTC) - RTC are commands that result in an immediate action on-board the spacecraft or a memory load. There are two types of RTC:

(1) Real Time Interactive Commands (RTIC) - Commands that affect the resources and/or operations of more than one spacecraft subsystem, the PDS or more than one instrument.

There are 3 types of RTIC: 1) Parameter updates/memory loads; 2) Single commands; and 3) Emergency commands.

(2) Real Time Non-interactive Commands (RTNC) - Commands that affect only one instrument and do not affect the spacecraft resources (within specified limits) and/or operations of other subsystems, the PDS or other instruments.

There are 2 types of RTNC: 1) Parameter updates/memory loads; and 2) single commands.

5.5.1 Deleted

5.5.2 Magnetometer (MAG)

5.5.2.1 Command Description. All instrument critical functions will be controlled via the "hardware decode command" capabilities of the PDS Bus Interface Unit (8 bits). All mode change commands will be implemented through the bus command capability of the BIU (n x 16 bits). It is anticipated that a single 16-bit word will be sufficient to implement all mode control functions.

Preliminary assignments for the 8-bit hardware decoded command functions:

Bit 7 (MSB): O = Outboard MAG 1 = Inboard Mag

Bit 6 - : Range MSB (4)

Bit 5 - : Range bit (2)

Bit 4 - : Range LSB (1)

Bit 3 - : Range Mode: 0 = Auto; 1 = Manual

Bit 2 - : Calibrate sequence: 0 = Off; 1 = On

Bit 1 - : Redundancy Select, Line 1 (Master Processor "A" RESET)

Bit 0 - : Redundancy Select, Line 2

Descriptive 16-bit software commands:

(1) Telemetry Mode = 1.5 kb/s

(2) Telemetry Mode = 3.0 kb/s

(3) Telemetry Mode = 6.0 kb/s

(4) Telemetry Mode = 12.0 kb/s

(5) 6-bit differencing ON/OFF

(6) Engineering packet format only

(7) Averaging mode ON/OFF

(8) Electronic Flipper Mode NORMAL/INVERT

(9) Memory load at parameter table address

(10) Memory load to program area

(11) ER calibrate mode

(12) ER MOI mode

5.5.2.2 Memory Load Size. The fundamental design philosophy implemented in the Mars Global Surveyor magnetic field experiment is the minimization of memory load functions. An executive program, (as well as a backup and diagnostic version of the same) resides in ROM and calls several table driven routines which also reside in ROM with limited access to RAM. Thus memory loads would be limited to parameter and calibration table updates of very small size (less than 1 kbyte).

5.5.2.3 Command Expansion and Timing Requirements. There are no requirements for command expansion in the MAG experiment.

It is a goal that the relative time of MAG packet collection with respect to mission time, should be known to within +10 ms.

5.5.3 Mars Orbiter Camera (MOC)

5.5.3.1 Command Description. Only five commands (power on, power off, bakeout heater on, bakeout heater off, and mode change) are transmitted to the instrument through the spacecraft and Payload Data System. All other operations of the camera are controlled by parameter uploads and updates to the instrument through non-interactive real-time commands.

There are 9 parameters shared by every data acquisition:

(1) Camera Select (1 bit): This selects between the wide angle or the narrow angle cameras.

(2) Gain and offset setting (4 bits): This parameter establishes gain and offset values or selects automatic gain control. The actual gain setting is part of an image record, and is always returned.

(3) Down-track dimension (16 bits): This parameter specifies the starting and ending values, in units of 16 lines, for the length of the image in the down-track dimension.

(4) Number of cross-track segments (3 bits): Allows segments of a CCD to be read out (e.g., limbs only, nadir only, etc.).

(5) Segment n Cross track dimensions (16 bits): This parameter specifies the cross-track starting pixel value and number of pixels for cross-track segment n.

(6) Sequence code for multiple images (8 bits): ID number of sequence to which image belongs (permits offsets of timing to be supplied once for a sequence determined by fixed offsets from one another).

(7) Coarse timing offset (24 bits): Establishes image acquisition timing to 125 ms accuracy.

(8) Fine timing offset (8 bits): Establishes image acquisition timing to 1 ms accuracy.

(9) Image buffer priority (4 bits): Establishes the priority of the image for buffer management.

There are an additional 3 parameters required to specify every wide angle acquisition:

(1) WA resolution select (8 bits): Selects resolution in 250 m increments.

(2) WA color select (2 bits): Selects red, blue or both colors.

(3) Software compression algorithm select (6 bits): Selects between software compression algorithms and compression tables.

There are an additional 5 parameters required to specify every narrow angle acquisition:

(1) NA detector select (1 bit): Selects between primary and secondary (backup) CCD detector.

(2) Context image size select (2 bits)o Selects between four different context image size and shape options.

(3) NA resolution select (4 bits): Selects resolution between 1 and 8 pixels.

(4) Hardware compression algorithm select (6 bits): Selects between hardware compression algorithms and compression tables.

(5) Software compression algorithm select (6 bits): Selects between software compression algorithms and compression tables.

Additional commands will support health and welfare monitoring (8 bits), general instrument housekeeping (8 bits), and error detection and correction (24 bits).

5.5.3.3 Command Expansion and Timing Requirements. None.

5.5.3.4 Uplink Data Rate Requirements. MOC uplink data rate requirements are divided into two categories: parameter uploads and parameter updates.

(1) Parameter uploads: These represent complete specification of each image acquisition. Approximately 150 bits are needed to specify each image. **Daily uplink bit requirements vary from a low of 1.5 kbits (kb) during low-rate record-only periods to 32 kb during high-rate record and realtime periods (MOC11).**

(2) Parameter updates: These represent modifications to existing sequences based on latest (best) available orbit determination predicts. Approximately 50% of the parameters will be changed. **Daily uplink bit requirements vary form a low of 0.8 kb during low rate record-only periods to 16 kb during high-rate record and realtime periods (MOC12)**.

5.5.3.5 Uplink Bit Error Rate Requirements. **MOC requires that the uplink bit error rate be better than 1 bit error in 10^5 bits received by the MOC (MOC13).** This rate includes all links from the MOC Operations Facility through the MGS Ground Data System, DSN, spacecraft receiver, and PDS.

5.5.4 Deleted

5.5.5 Mars Orbiter Laser Altimeter (MOLA)

All commands for the MOLA will be sent from the PDS via the dedicated Bus Interface Unit. Operation under normal conditions will only require a prompt/power-on command.

5.5.6 Radio Science (RS)

5.5.6.l Command Descriptions.

TELEMETRY ON/OFF

It shall be possible to command the spacecraft to turn off the telemetry data stream modulation on the carrier during radio occultation measurements (see RS9).

ULTRASTABLE OSCILLATOR AS FREQUENCY REFERENCE

It shall be possible to command the spacecraft TCS to a mode such that the frequency of the downlink carrier is derived from the USO without regard to the lock status of the uplink receiver(s) (see RS8).

RANGING ON/OFF

It shall be possible to command the ranging channel on and off. When the ranging channel is off, no ranging sidebands shall be present on the downlink signal (see RS10).

5.5.6.2 Command Memory Load Size. **When the DSN is tracking the spacecraft, the Radio Science experiment will require the execution of approximately six commands per orbit (RS22):** (i) and (ii) telemetry and ranging will be turned off just prior to occultation immersion; (iii) the TCS will be commanded to use the onboard USO exclusively as the frequency reference for the downlink carrier just prior to occultation immersion; (iv) following occultation immersion, the TCS shall be commanded to resume coherent tracking; (v) and (vi) telemetry and ranging will be turned on. Assuming that four orbits will be tracked each day, the Radio Science investigation shall require 24 commands per pass or 96 commands for a typical 3-day command load.

Table 5-12. Command Structure

Level 1: Mission Plan
Level 2: Orbit Schedule
Level 3- Sequence
Level 4: Observation
- Pointing Mirror Table - Digital Filter Table - Detector Mask Table - Spectral Mask Table - Repeat Count

5.5.6.3 Command Expansion and Timing Requirements. **The execution of preprogrammed commands shall be to an accuracy of less than 10 seconds (3σ) (RS23).**

5.5.7 Thermal Emission Spectrometer (TES)

5.5.7.1 Command Description. The TES instrument will be controlled using a hierarchical command structure and a simple language command. The command structure is summarized in Table 5-12. The command language will contain all of the commands required to control all instrument and processor activities. These activities will include: 1) set detector mask; 2) set spectral masks for center and edge detectors; 3) set up record raw interferograms; 4) execute observation, and 5) repeat observation. The observation parameters will set the mirror position and image motion compensation rates and the repeat count for the number of time steps to repeat the observations; for example, repeat nadir observations for 50 time steps. Using this scheme, Sequences will be constructed using the command language to set the detector mask, spectral masks, and then execute a series of observations to form a Sequence. An example would be to view space and reference, set detector and spectral masks to full resolution, view nadir for 100 seconds, view the limb, and conclude with a space observation. Other Sequence examples include limb observations, mosaics, and emission phase angle observations.

Orbit schedules will be constructed from a list of Sequences, each time to begin at a specified time from the equator crossing. Three Schedules will run in parallel: l) the Record Schedule; 2) the Real-Time Schedule; 3) the Overlay Schedule. The Record and Real-Time Schedules will be used for basic, repetitive sequence control, such as variations between day, night, and polar sequences. The Overlay Schedule will be used for specific, targeted observations, such as mosaics, that vary from orbit to orbit.

Finally, a Mission Plan will be constructed and stored within the instrument. It will contain the Schedules for the next 3 to 7 days of operation.

Using this scheme the TES instrument can be controlled completely internally using the minimum possible number of uplink words, yet utilizing the full, inherent flexibility of a microprocessor controlled instrument. Tables of approximately 32 different spectral masks, 7 detector masks, 128 mirror positions, 64 observations, and 256 possible sequences will be stored on-board the TES. From these approximately 16 Record and Real-Time Schedules can be constructed for any phase of the mission. Overlay Schedules will be constructed from a small subset of possible sequences, with time tags to control pointing.

Thus, the TES will be entirely table driven. Instrument commanding will consist of uplink information to update the Mission Plan and Orbit Schedules, and to occasionally change entries in the other tables. The amount of uplink data required to execute a single orbit will be 2 16-bit words to point to the Record and Real-Time Schedules for that orbit, plus approximately 10 16-bit words to construct the orbit-specific sequence and start-time lists in the Overlay Schedule **Thus, 12 16-bit words/orbit or 145 words/day will be routinely required for TES commanding. Additional uplink capability will be required to update the tables at 2-to-4 week intervals (TES14).** No storage of any of these uplink data within the PDS is required.

5.5.7.2 Memory Load Size. Memory loading will consist of: (1) updating entries in the Instrument Function Tables, the Instrument Command Macro Table, the Sequence Table, and the Orbit Set Table; and (2) updating onboard processor software. Table entries will be updated only as required to optimize the data science return, either in response to changing conditions on Mars or as experience with the experiment is gained. The memory size of Table entries varies from approximately 8 bits to approximately 144 bits. The memory size of Instrument Command Macro entries is 19 bits. The total memory required for all Table entries is 4000 bits. Thus the total memory load required to update all Tables is 4000 bits. Updates of portions of these tables will be required at 4 week intervals.

The onboard software memory size requirements are 16 kbytes. A complete read or write of this memory would be required only in the event of processor problems or changes.

5.5.7.3 Command Expansion and Timing Requirements. No command expansion within the PDS is required for the TES instrument. All command interpretation and expansion will be performed internal to the TES instrument.

5 6 DEEP SPACE NETWORK REQUIREMENTS

5.6.1 Radio Science (RS)

The Radio Science System of the Deep Space Network shall have the following capabilities for support of the Mars Global Surveyor Radio Science experiments.

5.6.1.1 Tracking Coverage. The largest possible data volume is needed to gain maximum resolution and separability of gravitational parameters for a large (up to 50 by 50) gravitational field model. Accordingly, the tracking of the mapping orbit should be as regular, continuous, and complete as possible using as many DSN sites as practical; at least one pass per day with a 34-m antenna is required (RS23). **Co**herent Doppler tracking data are strongly desired from 70-m ground antenna during real-time passes scheduled every third day.

It is the strong desire of the Radio Science Team to augment the nominal tracking coverage described above with three periods of intensive tracking. The first should occur just prior to initiation of the mapping phase, when the spacecraft should be placed in a gravity calibration orbit (GCO) with a repeat cycle of 7-10 days; the spacecraft should be tracked continuously (24 hours per day) over at least one full repeat cycle, and preferably throughout the biased GCO, the GCO and the spacecraft checkout period. During the mapping phase, two "gravity campaigns" are desired; in each of these, the spacecraft should be tracked continuously over a full repeat cycle at three separate times whose spacing is one third of a mapping cycle. Figure 5-1 shows the preferred times for intensive tracking coverage. See Section 3.2.6 for further discussion.

If 24-hour tracking coverage is not available and the nominal tracking schedule makes extensive use of a single ground station, data reduction will become difficult due to effects associated with the wobble of the Earth's pole. At the same time, full resolution global coverage will accumulate relatively slowly under these circumstances due to the near equivalence of the rotation periods of Earth and Mars. For these reasons, it is highly desirable to switch tracking stations regularly. Details of scheduling are presently being studied to minimize station switching while still acquiring fast, even global coverage.

5.6.1.2 General Ground Data System Requirements. **Media calibration data concerning the local environment of the DSC, are required to support the Radio Science Investigations (RS25)**.These include ground weather data (wind speed and direction, precipitation rate and accumulation and near-surface temperature, pressure, and dew point temperature) as well as the total electron content of the terrestrial ionosphere. **Supplementary calibration data are needed to characterize equipment performance (system noise temperature) and the experimental geometry (antenna elevation angle) (RS26).** All quantities mentioned above should be sampled at intervals of about 1-5 minutes (TBD) throughout MGS station passes including Radio Science experiments. **These calibration data shall appear as a file (or files) in the MGS Project data base in a format TBD (RS27).**

The DSN shall provide a Timing and Polar Motion File containing best estimates of the rotation rate and pole vectors of the Earth. Regular updates shall be provided as new information becomes available (RS28).

Selected ground monitor data shall be processed and displayed in real time whenever the spacecraft is tracked for purposes of Radio Science calibrations or experiments (RS29). These data shall be supplied by the DSN to the Project Data Base and shall include:

(l) the spectrum of the carrier signal in the passband of the open-loop receiver throughout each applicable DSN station pass;

(2) the receiver AGC;

(3) the status of the Radio Science Subsystem;

(4) a plot showing the time history of the two-way Doppler residuals based on the best available DSN frequency predictions;

(5) the status of transmitter operation;

(6) a log of significant Radio Science events (e.g., 5 times of acquisition and loss of signal)$

(7) tracking data and tracking system monitor data

(8) the drive level of A/D converters.

5.6.l.3 Gravitational Measurements. **The observations shall be performed under the following conditions**:

S/C CONFIGURATION:

(1) **Two-way coherent tracking mode;**

(2) **Ranging channel on.**

GROUND CONFIGURATION:

(1) **Recording of closed-loop data;**

(2) **Doppler sample rate of 1 sample per 10 seconds;**

(3) **Recording o£ ranging data at a rate of one sample per 10 minutes (RS30)**.

When the spacecraft is in the nominal two-way coherent tracking mode, the contribution by DSN equipment to the Doppler noise shall be no more than TBD mm/s for a 10-second integration time (0.1 mm/s (3σ) for a 10-second integration time is the goal).

The uncertainty in range measurements caused by DSN equipment should not exceed 3 meters (3σ-goal).

Subreflector focusing shall be performed in a manner that is consistent with the Doppler noise goal given above (RS31). For example, in one scenario, the subreflector could be confined to a fixed position during all periods of two-way tracking, thereby avoiding any degradation of Doppler tracking data. The subreflector could then be adjusted to the optimum position for the next orbit when the spacecraft is geometrically behind Mars, after occultation measurements at immersion are completed but before measurements at emersion begin. On the other hand, during phases of the mission where Earth occultations are absent and the spacecraft can be tracked continuously, subreflector refocusing could be performed in short, discrete events that occur as infrequently as possible. In either case, the time and magnitude of all changes in subreflector position shall be recorded and provided to the Radio Science Team via the Project Data Base.

In the interest of the gravity investigation, **the DSN should strive to minimize the time required to lock up in the two-way Doppler tracking mode following any period in which the spacecraft signal is either absent or referenced to the onboard USO (RS32)**.

Although not a requirement at present, ΔVLBI data are highly desirable for the gravity investigation and are requested if they are readily available. **Radio metric data shall be provided in the form of Archival Tracking Data Files (ADTFs), and Orbit Data Files (ODFs) (RS33)** (see Section 5.7.6).

5.6.1.4 Atmospheric Measurements. **The DSN shall acquire data from all The DSN shall acquire data from all occulations of the spacecraft by Mars that occur within DSN station passes allocated to the Mars Global Surveyor Mission (RS34).** This will include about 4 pairs of occultations (immersion plus emersion) per pass (exact value TBD).

The observations shall be performed under the following conditions:

S/C CONFIGURATION:

(1) **Telemetry modulation off;**

(2) **Ranging channel off and VLBI channels off;**

(3) **Onboard USO as frequency reference for downlink signal during all occultation events**.

GROUND CONFIGURATION:

(1) **Recording of open-loop data;**

(2) **Recording of closed-loop data; (USO one-way Doppler data)**

(3) **Doppler sample rate of 10 samples per second (RS35);**

The MOS shall provide the DSN with orbit ephemeris predictions including occultation event times 5 days in advance of the relevant station pass (see section 3.3.6) **(RS36). The DSN shall then generate Radio Science prediction on the basis of this ephemeris with the guidance from the Radio Science Team (RS37)** (e.g., the RS team will provide a value for the best lock frequency of the USO)O The prediction shall consist of start and stop times for open-loop recording intervals as well as predictions of the received X-band carrier frequency throughout the station pass for use in tuning the open-loop receivers. (During occultation experiments, the effect due to the atmosphere of Mars is not expected to exceed about 5 Hz; hence, the atmosphere can be ignored in computing the frequency of the X-band carrier.) **The DSN shall provide the Radio Science prediction to the MGS Project Data Base 3 days in advance of the applicable station pass (RS38)** in order that the Radio Science Team can verify the sequences.

The Radio Science System shall be able to tune open-loop receivers based on the Radio Science Predicts to maintain the Mars Global Surveyor X-band carrier in a 0.2-to-2-kHz passband (value TBD) for an entire pass. **The Radio Science System shall be capable of storing the tuning predicts for up to 3 days (consistent with MGS operations) in advance of the applicable Mars Global Surveyor tracking pass (RS39)**. The actual tuning executed by the receivers shall be in the form of a continuous curve of frequency vs. time that remains within 10 Hz of the predicts at all times; the executed tuning curve shall be stored digitally to an accuracy of TBD Hz and shall be provided to the MGS Project Data Base as part of the open-loop EDR (Section 5.4.6).

The start and stop times of all recordings shall be commanded by the Radio Science prediction (RS40). The recording interval for each occultation event (immersion or emersion) shall include: (i) the extinction of the signal by the surface of Mars including 20 s of data taken while the spacecraft is geometrically "behind" Mars, (ii) data from the surface to 200 km altitude, (iii) a baseline interval (~100 s) during which the signal from spacecraft to Earth passes above 200 km altitude, and (iv) an appropriate time pad on both ends of the interval just defined to protect against timing uncertainty. For nearly diametric occultations, the entire radio occultation recording interval will span about 5 minutes. In the grazing occultation geometry, the upper altitude (200 km) may be reduced (value TBD) to accommodate tracking requirements.

During each occultation event (two per orbit), the Radio Science System shall digitally record the output of the open-loop receiver with a data

information bandwidth of 0.2 to 2 kHz (value TBD) (RS41). The data are to be stored digitally using 12 bits per sample. The sampling rate shall be at least twice as large as the data information bandwidth (RS42). The sampling rate shall also be accurate in a fractional sense to at least TBD. The time interval between adjacent samples shall remain constant to within TBD seconds. The data record shall include time tags with an absolute accuracy of TBD seconds and a relative accuracy consistent with the sampling rate requirements. The recorded data shall appear in the Project Data Base as part of the Open-loop EDR (Section 5.4.6) within 2 hours after the end of the station pass.

All steps involved in acquiring radio occultation data at the DSC, and transferring these data to the Project data base shall be reliable enough to ensure that 95% of the data acquired is "error free." The requirements should be interpreted in the sense that data acquired is "error free." The requirements should be interpreted in the sense that data acquired from 19 out of 20 occultation events (immersion or emersion) shall be recorded and delivered with a bit error rate of 10^{-7} or less; it would be unacceptable if 5% of the data from every occultation event (RS43) were corrupted.

During all occultation experiments (both immersion and emersion), pointing control of the ground antennas shall be accurate enough to limit any resulting variations in the intensity of the received X-band signal to a peak-to-peak level of 0.1 dB or less. Such pointing must be performed without the use of any signal-level feedback mechanisms (such as CONSCAN) (RS44). This requirement is independent of other experimental effects on the signal level.

The position of the sub reflector shall remain fixed within all occultation observation intervals (duration 5 minutes) (RS45).

After calibration, the overall amplitude stability of all DSN equipment involved in open-loop recordings shall be 0.1 dB or less over a period of 5 minutes, independent of both antenna pointing and any experimental effects on signal level (RS46).

The DSN shall be capable of determining the absolute frequency of the X-band carrier received from the spacecraft using an integration period of TBD seconds with a fractional accuracy of TBD. Signal-to-noise ratio effects are excluded.

During periods when the downlink signal from the spacecraft is derived from the onboard USO, the uncertainty in the determination of the X-band carrier frequency shall have an Allan variance of less than TBD for an integration of TBD seconds.

For a pure sinusoidal input signal, the phase noise spectrum due to all DSN equipment involved in open-loop recordings shall be (1s) less than or equal to (see 4.3.6.4):

Frequency, Hz	Single Sideband Phase Noise spectrum dBc/Hz
1	TBD
10	TBD
100	TBD
1000	TBD

The signal-to-noise spectral density of all equipment involved in open-loop recordings shall be greater than 75 dBc per Hz within 2000 Hz of the carrier (RS47).

The phase delay and group delay of the open-loop equipment shall charge by less than TBD degrees over any 300-second interval.

Simultaneous to the acquisition of open-loop data during the occultation experiments, one way Doppler data shall be generated in the form of radiometric data and transmitted in real-time to the Project Data Base (as a backup in case of failure of the open loop system) (RS48).

5.7 EXPERIMENT DATA RECORDS

At least 85% of all data acquired and recorded or transmitted real-time by the spacecraft shall be returned to the investigators. An amount of >95% of the data received by a DSN station shall be recovered and may be subject to recall.

5.7.1 Deleted

5.7.2 Magnetometer (MAG)

Although the project baseline is the "electronic" transfer of EDR's to the remote investigator facilities, previous experience with electronic data transfers and the reliability of data lines, suggest that an alternative and complementary method of data delivery be implemented for Mars Global Surveyor. Some real time support may be required during special periods or emergencies such as initial turn-on or spacecraft anomalies/ maneuvers. The MAG experiment assumes that 95 percent of the total number of packets received at the DSN during the mission will be delivered to the experimenters for further processing and deposition in the project data base. **The maximum acceptable bit-error rate in the delivered data is 10^{-5} (see MAG26).**

For the EDR/SPICE transferred electronically to GSFC, the transmission rate should be at least 4 times the MAG data acquisition periods (MAG28).

EDR's should be made available to GSFC within 30 days of the acquisition of data (MAG29) If necessary, final EDRs should be received at GSFC no later than 90 days after data acquisition.

Final SPICE data including attitude and spacecraft position information should be sent to GSFC within 30 days of acquisition of data (MAG30).

5.7.3 Mars Orbiter Camera (MOC)

5.7.3.1 Quantity, Quality, and Continuity. Based on mission average (mean) and high rate record + real-time data (maximum) data rates, data quantities for the MOC experiment are estimated as follows:

(1) Data Rates:

Mission Average data rate	7,510 bps for 24 hr = 649 Mbits per day
Maximum data rate	9 kbps for 24 hr + 11 kbps for 12 hr + 29.4 kbps for 4 hr = 1,287 Mbits per day

(2) Compression Ratios:

Minimum compression ratio	1:1
Noiseless compression (software)	3:1
Compression with noise (hardware)	2:1
Compression with noise (software)	8:1, 16:1, 32:1
Assumed average compression ratio	5:1

(3) Total Data Return:

The MOC experiment will acquire approximately 4.6×10^{11} bits during the nominal mission. Decompressed, this value approaches 2.2×10^{12} bits;

(4) Delivery and Bandwidth Requirements:

All MOC data shall be delivered by the Project to the MOC Operations Facility at a rate commensurate with that at which it is returned from the spacecraft (MOC14). The appropriate and/or available SPICE kernels are required within 14 days of this data delivery (MOC15). MOC requires that data delivery be nearly continuous (MOC16).

In order to meet the requirements of the MOC experiment, a maximum JPL to MSSS bandwidth of about 20 kb, 24 hours a day, 7 days a week, is needed. This consists of raw data (~15 kbps), navigation data and SPICE information (~3 kbps), and housekeeping traffic (2 kbps). For 8 hour days and 5 day weeks these numbers are about 67 kbps (JPL ->MOC) and 80 kbps (MOC ->JPL).

A higher baud rate is probably required based on the overhead associated with transmission. Thus, the 2-way MOC communication link, under the 8-hr/5-day assumption, may approach 224 kbaud.

5.7.3.2 Database Inputs. The record of the MOCs packet telemetry, contained within a SFDU, must be delivered by the Project to the Project Data Base in a continuous manner, and **all data must be delivered within 24 hours of ground receipt (MOC17)**, consistent with the Mars Global Surveyor Mission Operations Plan (JPL Document 642-32).

A record indicating that the MOC Investigation Team (MOC IT) has received and accepted the data record will be logged within the Project Data Base upon verification of the data record. Engineering information pertaining to the health and performance characteristics of the MOC, derived from the engineering data embedded in the MOC data stream and based on analysis by the MOC IT, will be placed within the Project Data Base on a regular basis.

The amount of storage required by the Project Data Base and the Instrument Data Base can be estimated using the rates described above and the following values:

(1) Compressed data:

1 mapping cycle (56 days) @ average data rate (46 MB/day) = 2.6 GB

687 day nominal mission @ average data rate (46 MB/day) = 32 GB

(2) Uncompressed data (x5 expansion):

1 mapping cycle @ average data rate (46 MB/day) = 13 GB

687 day mission @ average data rate (46 MB/day) = 160 GB

5.7.3.2.1 EDR. The MOC data will be highly compressed, and decompression will cause an average of 5-fold expansion, with factors in excess of 20 possible for large amounts of data. Creation of multiple, standard products would cause even greater expansion. The MOC is not presently planning to "expand" its data for return to the Planetary Data System. The plan is to return data in essentially the same form in which it is delivered, that is, in compressed format. The data will be unpacked but otherwise unprocessed. The available SPICE information will be transmitted along with the compressed images. Pre-launch calibration files and decompression algorithms will be supplied to the data bases at an earlier date. This is all that presently constitutes the MOC EDR.

5.7.3.2.2 RDR. Reduced Data Records are discussed in paragraph 7.3.3. It is noted here, however, that MOC RDR will consist primarily of calibration files and decompression algorithmic keys. Occasional, special purpose observations of limited quantity may be delivered in decompressed and calibrated format, that is, as real 2D arrays or images.

5.7.3.3 Delivery Address and Recall Constraints. **All MOC image data must be recallable within thirty days of delivery to the MOC Operations Facility (MOC18)**.

5.7.4 Deleted

5.7.5 Mars Orbiter Laser Altimeter (MOLA)

This investigation requires that 95 percent (98% goal) of the experimental data records received at the ground stations be returned, with no data gaps or record losses exceeding one packet in length (MOLA8). If data losses are higher than this, special effort should be made to retrieve the missing data in order to provide a complete data set for this investigation. All data will be accessed through the workstations, including any retrieved data not originally provided.

5.7.6 Radio Science (RS)

(1) Quality, Quantity, and Continuity

Occultation Measurements. Requirements on the quality and continuity of the data are discussed in Section 5.6.1 (Requirements on the DSN).

The occultation measurements constitute a multitude of extremely similar events occurring as often as about one per hour. This implies the need for a simple, reliable system that can be set up and operated on a routine basis with minimal operator intervention.

The quantity of data from Radio Science studies of the atmosphere is not large. In the worst case, a few times 106 bytes of raw data per occultation event (a single immersion or emersion) are required with more likely values in the range of 106 bytes. (The present range in values arises from uncertainties in the implementation and operational procedures that affect necessary guard times and bandwidths. The amount of data is highly dependent on the details of implementation.) It is the intent of the Radio Science team to record data from about 4 complete occultations (immersion plus emersion) during each pass of a DSN station allocated to the Mars Global Surveyor Mission.

The Mars Global Surveyor Project shall take those actions necessary to reduce data load from the occultation measurements to a minimum (RS49).This includes primarily the prediction of occultation times and frequencies to within about 10 seconds and 300 Hz, respectively (goal)O This should restrict raw data files to a size no larger than approximately 106 bytes, which are then consistent on a per orbit basis with those of baseline on-board instruments.

Gravitational Field Measurements. The quantity, quality, and continuity of the tracking data have already been discussed in Sections 3.2.6 and 5.6.1.

(2) Data Base Inputs

In the past, it has been customary to deliver both closed-loop and open-loop EDRs (as defined below) to investigators in the form of computer compatible magnetic tapes. The MGS Radio Science Team strongly prefers to have these and all other data products listed below delivered as electronic files in the MGS Project Data Base, where they will be accessible to investigators from Project-supplied workstations.

Beyond the specific items listed below; the Radio Science Team requests access to all data products acquired for the Navigation Team's orbit determination. Specifically, these include, but are not limited to, all tracking data from the biased GCO, the GCO, and the spacecraft checkout period prior to initiation of the mapping phase, and all differential VLBI data.

(1) Closed-Loop EDR - The Closed-Loop Experiment Data Records shall be electronic files in the MGS Project Data Base containing Doppler, range, the absolute frequency of the received X-band carrier, VLBI data, and monitor data concerning the closed-loop receiver status collected during DSN tracking passes of interest to Radio Science Team investigators. **The closed-loop EDRs shall be delivered to the Project Data Base in the form of Archival Tracking Data Files (ATDFs--raw data), and Orbit data Files (RS50) (ODFs-- combined, compressed**, and validated versions of ATDFs).

(2) Open-Loop EDR - **The Open-Loop Experiment Data Records shall be electronic files in the Mars Global Surveyor Project Data Base (RS51)** containing bit-by-bit reproductions of the original data recorded by the DSN (see Section 5.6.1).

(3) Radio Science Predicts - The Radio science Prediction shall be used by the DSN to tune the open-loop receivers of the **Radio Science Subsystem and to control the start and stop of data collection by the recorders (see Section 5.6.1.4). A copy of each prediction set** (i.e., the prediction for one tracking pass) **shall be made available to Radio Science investigators in Electronic form on the mission**

data base 3 days in advance of the applicable tracking pass (RS52).

(4) Spacecraft Engineering EDR - **The Spacecraft Engineering Experiment Data Record shall be an electronic file on the Mars Global Surveyor Project Data Base (RS53).** It shall contain data from selected spacecraft engineering telemetry channels needed to calibrate and reduce the closed-loop and open-loop data.

(5) Media and Supplementary Calibration EDR - **The DSN shall deliver media calibration data on the Earth's ionosphere and troposphere and supplementary calibration data concerning DSN equipment (antenna elevation angle, system noise temperature, and subreflector focusing) to the MGS Project Data Base for all Radio Science data types (RS54)** (see Section 5.6.1.2).

(6) SPICE+NAIF Kernels - This tool is an electronic file with supporting software on the Mars Global Surveyor Project Data Base containing spacecraft and Mars state vectors as computed by the Navigation Team based upon a posterior orbit determinations (format and scope of files TBD).

(7) Attitude Reconstruction SEDR - It is desired that an Attitude Reconstruction Supplementary Experiment Data Record, an electronic file on the Mars Global Surveyor data base, contain HGA electrical boresight pointing vectors as well as the position and velocity of the HGA electrical phase center relative to the spacecraft center of mass as computed by the Mission Operations Team, based upon attitude control system telemetry.

(8) Orbit Determination Data Products - The Radio Science Team requests access to the following data products pertaining to orbit solutions and the Martian gravitational field:

(a) Measured times of Earth occultations of the MGS spacecraft on every available orbit (from within Radio Science Team);

(b) Measured times of solar occultations of the MGS spacecraft (both immersion and emersion) in every available orbit to an accuracy TBD of (0.01 seconds goal);

(c) Altimeter data (from Altimeter Team).

(9) Hardcopies - **Hard-copy records of NOCC logs and DSN station status printouts shall be required from the DSN on request (RS55).** These will include all printouts made at the tracking station showing monitor data on the functional status of hardware and software.

(10) Orbit predictions - **Mapping orbit ephemeris predictions shall be generated by the Navigation Team for purpose of experiment planning and for use by the DSN in computing Radio Science prediction (RS56) (item 3)**. These shall include predictions of occultation event times as defined in Section 3.3.6.

(11) Planet and Satellite Ephemerides - Position and velocity vectors and rotation axis vectors for Mars, Phobos (TBD)9 Earth and Sun as functions of time for use in studies of the gravitational fields.

(12) Timing and Polar Motion File - File of best estimates of past and future Earth rotation and polar motion changes provided by the DSN.

5.7.7 Thermal Emission Spectrometer (TES)

The quantity of experiment data records will vary with the output rate of TES instrument. At the two proposed rates of 688, 1664 and 4992 bps, the TES instrument will produce data at rates of 6.1 x 107 and 4 x 108 bits/day. At the time of ground processing to be done at Arizona State University, the data will he decompressed, which will expand the volume of data by approximately a factor of 3 from the amount downlinked. In addition, the data will be converted from 10-bit emissivity values to 16-bit calibrated radiance values for compatibility with standard computer systems and geometry values will be attached. This expansion will result in an approximately 30-fold increase in the data volume, or approximately 1.5×10^9 and $3.5 \times l0^9$ bits/day stored at ASU and returned to the Project data base. Over the 687-day duration of the mapping mission, these rates will produce totals of 10^{12} and 2.4×10^{12} bits, respectively.

The quality requirements are for a bit error rate within the spectra, as received at the data processing facility at ASU, of 10^{-5} or better (TES15).

The TES instrument will only complete 2.5 mapping cycles during the mapping phase, assuming a best-case observing strategy of all three crosstrack IFOVs operating simultaneously. Therefore, **the data must be 85 (95-97 goal) percent complete in order to accomplish the mapping of the TES experiment. Data gaps should be randomly spaced (goal), with no single gap of more than one orbit (TES16)**. Critical observations will occur during the instrument performance evaluation, during the transition orbit, at the beginning of the mapping mission, and during a variety of atmospheric conditions, such as the onset and decay phases of the global dust storms.

<u>Database Inputs</u> - Standard products will be produced as part of the standard TES processing. The standard set of products will consist of:

(1) Calibrated radiance values from each of the interferometer, solar reflectance, and bolometric radiance ;instrument sections, together with the geometry location of acquired data, either as specific values, or with the associated SPICE kernel information necessary to reconstruct these values. These data will be in the form of "image cubes". Calibration shall consist of: (a) removal of the instrument response function; and (b) absolute calibration of the radiance. The spectral.

editing and averaging accomplished within the instrument will be reconstructed so that easily interpretable spectra are returned to the Database.

(2) Spatially resampled versions of the data described in (1) above. Resampling will conform to the Mars Consortium (or other Project-specified) format.

(3) All instrument calibration data and instrument performance information.

Additional data products will be generated as part of the analysis performed by the TES Science Team. However, because of funding limitations, these products will not be generated for all returned data, nor as part of a regular, systematic data processing function. These data products will be returned to the Project Database on a negotiated level and timescale, consistent with the available resources. Examples of these data products include:

(1) Global maps of derived geophysical properties, including: (a) surface composition; (b) soil components; (c) albedo; (d) thermal inertia; (e) rock abundance; and (f) polar ice cap location. These maps will be updated at appropriate intervals as data are received and processed.

(2) Derived atmospheric quantities including: (a) temperature profiles; (b) atmospheric dust opacity; (c) H_2O and O_3 abundances; (d) surface pressure variations; and (e) water ice cloud occurrence.

(3) Individual mosaics constructed from a single observing sequence.

The TES investigation will use data produced by other MGS experiments, as agreed to in advance according to the policies adopted for access and exchange Products of particular importance will include.

(1) MOC high-resolution images of specific targets planned for joint TES and MOC observation.

(2) Radio science temperature profiles.

Delivery Address and Recall Constraints

Ground Communications

From JPL to ASU: Data delivery will include the raw downlink (EDR), plus the geometry predicts and knowledge, plus all information related to uplink planning and project management. We estimate that the total data rate from JPL to ASU will be 2 times the downlink telemetry from the spacecraft, plus 1 Mbyte per day.

From ASU to JPL: Data returned to JPL will include the decompressed raw data, calibrated data that have not been spatially resampled, data spatially resampled to a uniform Mars cartographic system, maps of derived parameters, plus information related to uplink planning, instrument calibration and performance, and project management.

The data expansion factors for the volume of data returned to the Project Database are approximately 3 for decompression (i.e., removal of the | compression performed onboard the TES instrument), 1.5 for calibration and reformatting to 16 bits per spectral radiance point, 3 for spatially raw, spatially resampled, and derived parameters, resulting ;n a total expansion I factor of 22. In addition, approximately 1 Mbyte per day of planning, | calibration, and management information will be transmitted.

For a TES nominal data rate of 1000 bps continuous (nominal 688 recorded plus periodic 4992 real-time), and assuming that all communications will be performed during a 40-hour work week, the data volumes described above result in a communication throughput of:

(1000 bps * 25) x (24 hr * 7)/40 hr = 105 kbps

The data will be received from the MGS Project Data Base for processing at Arizona State University. The processed data, in the form of calibrated radiance values and pointing geometry (SPICE kernels) will be returned to the Project Data Base for distribution to appropriate Project investigators using a 56-kbps dedicated line. Because of the volume of data involved, TES Co-Investigators will either access the major volume of data directly from the Project Data Base, or using high--density medium for non-electronic transfer from ASU.

5.8 PLANNING AIDS

5.8.1 Deleted

5.8.2 Magnetometer (MAG)

SPICE prediction information should be made available to the MAG experiment team at least 60 days in advance of anticipated events or mission phase starting date (MAG13). It is highly desirable to obtain as accurate as possible predict products such that adequate planning for high activity periods can proceed in a timely fashion.

It is requested that EDR and SPICE "test" data (tapes or equivalent media) for each spacecraft data format be made available approximately 9 months prior to launch in order to expedite data processing verification/certification activities.

It is assumed that mission operation schedules and command load generation activities will be coordinated by the Project through the Remote Workstation (Science Operations Planning Computer) communication facilities.

5.8.3 Mars Orbiter Camera (MOC)

Certain mission planning aids are required from the project by the MOC: mission sequence plans, mission sequence schedules, and orbit/viewing forecasts. A schedule of Project and spacecraft events (e.g., uplink windows, orbit sustenance maneuvers, etc.) and accurate orbit determination predictions must be available before the actual MOC observations can be planned. Of particular importance is information on commanding opportunities for periods from approximately 30 days prior to execution through 3 days prior to execution (MOC19). Predictions of ground tracks should be available at all times, and should be updated during the planning process as orbit determination permits (MOC20).

These planning aids should be available in workstation-compatible computer code, with a relatively simple hard copy back-up capability (MOC21). The operational software must be available in time to support creation of the MOC-specific software (MOC22).

The offset of spacecraft time from UT must be provided to an accuracy of at least 20 ms once every 7 Earth days, in support of the sequencing activity (MOC23) (10 ms goal).

In addition to the planning aids listed above, the MOC IT desires the following products from the Project to support its planning and data analysis efforts:

Digital Data Desires

(1) Full resolution digital version of the USGS/Viking Orbiter Mars Global Photomosaic in 6250-bpi digital tape format.*

* or in CD-ROM format, provided the Project also provides one or more CD-ROM players

(2) Digital versions of USGS 1:5M airbrushed shaded relief maps (MC-l through MC-30), scanned at a spatial resolution of better than 3 km/scanned pixel (a map reduced to a 9 x 9-inch film and scanned at 100 µm would meet this requirement, including two versions of each map (shaded relief without longitude/latitude grid and without areographic nomenclature, and one with areographic nomenclature), in 6250-b/i digital tape format.*

(3) Digital versions of USGS 1:5M airbrushed albedo maps (MC 1 through MC-30), scanned at a spatial resolution of better than 3 km/scanned pixel (a map reduced to a 9 x 9 inch film and scanned at 100 µm would meet this requirement), including two versions of each map (shaded relief without longitude/ latitude grid and without areographic nomenclature, and one with areographic nomenclature), in 6250-b/; digital tape format.*

(4) Digital versions of all USGS airbrushed maps at map scales larger than l:5M (i.e., any maps produced at 1:2M, 1:1M, 1.250K, etc.), scanned at a spatial resolution appropriate to that map reduced to a 9 x 9 inch film and scanned at 100 µm, including two versions of each map (shaded relief without longitude/latitude grid and without areographic nomenclature, and one with areographic nomenclature), in 6250-b/i digital tape format.*

(5) Digital versions of all USGS digital photomosaics produced as scales and resolutions better than the Global Digital Mosaic, in 6250 bpi digital tape format.*

(6) Digital versions of selected Viking Orbiter images, provided by JPL on a pre-request basis in 6250-b/i digital tape format, or over the JPL to MSSS communications link.

<u>Hardcopy Data Desires</u>

(1) Complete set of USGS airbrushed map products of Mars (1:25M, 1:15M, 1:5M, 1:2M, and larger scales), reproduced at true scale on stable, base material (Kronopaque™. Cibachrome™, or comparable material).

(2) Complete set of USGS airbrushed map products of Mars (1:25m, 1:15M, 1:5M, 1:2M, and larger scales), in 4" x 5" negative film format.

(3) Complete set of USGS photomosaic map products of Mars (1:25M, 1:15M, 1:5m, 1:2m, and larger scales), reproduced at true scale on stable-base material (Kronopaque™, Cibachrome™, or comparable material.)

(4) Complete set of USGS photomosaic map products of Mars (1:25M, 1:15M, 1:5M, 1:2m, and larger scales), in 4" x 5" negative film format.

(5) Complete set of Viking Orbiter images in 5" strip contact print (SCP) format (cut).

(6) Complete set of Viking Orbiter images in 5" negative format (cut).

5.8.4 Deleted

* or in CD-ROM format, provided the Project also provides one or more CD-ROM players

5.8.5 Mars Orbiter Laser Altimeter (MOLA)

For purposes of reducing the acquired MOLA data we require the following from the project (see MOLA7):

(1) **Orbit prediction data**

(2) **Attitude data from the spacecraft**

(3) **Predicted and determined footprint information from other instruments (MOLA9).**

(4) **Time tags and selected data as provided by the MOC and TES (MOLA9)**.

5.8.6 Radio Science

5.8.6.1 **Planning Aides Required by RS**

(1) **A table listing the predicted areocentric latitude, longitude, and radius of Earth occultation points throughout the mapping phase of the mission;**

(2) **Views of Mars showing the locations of the Earth occultation points and including pertinent surface features, such as the estimated locations of the polar cap boundaries (perspective views: goal);**

(3) **A DSN schedule of station coverage and antenna allocation for the MGS mission including significant event times (e.g., Mars at 10º elevation), the maximum elevation angle, and the Mars-Earth-Sun angle for each station pass.**

(4) **Predicted times of immersion and emersion for all Earth occultations.**

(5) **Telecommunications link predictions, including expected signal strength and Mars-Earth-Sun angle;**

(6) **Plots of ground tracks on Mars maps (Mercator projections) with time tags of events (RS57).**

5.8.7 Thermal Emission Spectrometer (TES)

The planning aid needs are divided into the three mission phases; cruise/approach, transition, and mapping.

5.8.7.1 Cruise/Approach Phase. As described in Sections 3.2.3.3.7 and 5.1.7, observations of Mars during the approach phase are highly desired for calibration of the instrument off-axis response. Targeting predictions of Mars and the spacecraft will be required to align the spacecraft as described in Section 3.2.7 and to point and articulate the TES pointing mirror.

Complete knowledge of the instrument pointing relative to the sun will be required to avoid possible damage by accidental viewing of the sun (if approved).

5.8.7.2 Transition Phase. Observations of the satellites Phobos and Demos are highly desired during this phase and will require accurate predictions of the spacecraft and satellite ephemerides. The pointing requirements, described in detail in Section IV.C.1, are for predictions of the spacecraft and satellite positions to a combined uncertainty of ±4.1 mrad along the X and Y axes.

Observations of Mars are also desired during this phase. These observations will require orbit predictions and planning aids similar to those used in the mapping phase, and will provide a means of testing these aids in actual use.

5.8.7.3 Mapping Phase. A wide range of planning aids are required for the mapping phase. These include:

(1) **Orbit predictions and projected groundtracks.**

Standard predictions of orbit information at 30 day intervals will be required for planning (TES17). Updates 7 days prior to data acquisition are highly desired.

(2) Planning software.

To aid in mission planning a variety of software tools are required. The intent of these tools is to provide an efficient environment in which to maximize the return of the TES investigation and to maximize the synergism between TES and the other MGS experiments. These tools would be used to (1) **overlay predicted MGS groundtracks for planning TES mosaics of regional areas**; (2) **compare previous TES observations** in space and time to aid in planning multiple or complementary observations. For example, surface phase function or surface pressure observations of a specific region space throughout the mission; (3) **to maximize the use of real-time data to fill** in gaps in previously acquired data; (4) **to plan mutual observations with PMIKRR, MOC and radio occultations.** Specific examples of the types of software that would be useful include.

(a) **Groundtrack projection on sinusoidal equal area projections,** and on a perspective view of the planet (goal).

(b) **The position of the sun relative to the spacecraft reference frame at all points in the MGS orbit.**

(c) **Multiple overlays and combinations** of a wide range of products including; i) digital data bases, ii) ground-**tracks**; iii) **previous observations**; iv) real-time downlink availability as a function of groundtrack position and orbit; v) proposed pointing of the MOC instrument relative to TES for planning joint observations.

(d) Software for planning the targeting and acquisition of TES mosaics, including **variations in spacecraft altitude and orbital velocity, using the digital photomosaic for targeting (TES18**).

(3) Digital data bases

The following digital data bases are required (preferably on CD-ROM, except item (c). The ability to interface these data bases with the planning software to plan observations of specific geologic, morphologic, or thermal targets is required.

(a) **The USGS-generated digital photomosaic**.

(b) **Digital topographic information (TES19)**.

(4) Cartographic data bases.

The following cartographic products are desired.

(a) Complete sets of 1:5,000,000 topographic, shaded relief, and geologic maps, 1:2,000,000 photomosaic maps, and 1:15,000,000 topographic, shaded relief, and geologic maps.

(b) Two sets of hardcopy prints and 1 set of negatives of the USGS-generated digital photomosaic.

(c) A complete set of Viking Orbiter camera SCP's.

(5) Satellite ephemerides.

Predictions of the positions of Phobos and Demos relative to the MGS spacecraft inertial reference frame, together with the software necessary to predict and plan TES observations of these satellites are desired. The software must be capable of predicting these locations from both the transition and mapping orbits.

(6) Input from MOC and other sources on dynamic phenomena.

Input from the other MGS instruments in near-real time is highly desired for planning purposes. These inputs will be especially useful for acquiring data on dynamic surface and atmospheric phenomena, including dust storm development, polar cap formation and retreat, and atmospheric condensate occurrence. Quick response to dynamic changes will permit the greatest science return from the Mars Global Surveyor mission.

(7) Network communication link to all TES Co-Investigators and to all other MGS instrument teams for coordinated observations via TBD provision is desired.

5.8.8 Interdisciplinary Science (IDS)

5.8.8.1 Arvidson. The Project should provide the capability to graphically overlay acquired and planned Mars Global Surveyor data on sinusoidal equal area projections, as labeled groundtracks and footprints. Further, this capability should be available at user Home Institutions on the Project-supplied workstations. The global Mars Viking digital mosaic should be used as an optional background display for the overlays (goal).

5.8.8.2 Carr. The following is a partial list of aids **needed for planning at the start of each planning cycle.**

(1) **Orbit track overlays on digital data base.**

(2) **Illumination conditions along orbit track.**

(3) **Previously acquired MGS data in both digital and analog (map) format (goal).**

(4) **Viking-based digital imaging data base (IDS5).**

5.8.8.3 Ingersoll. A requirement for the SPICE, from which the observation sequences will be planned, is that it be simple and universal. One should not let the number of items on the SPICE grow beyond the basic set that specifies spacecraft position and attitude vs. time. Derived quantities, such as what the instrument is looking at, should be left off. This way everyone will have the same SPICE, and the SPICE will be easier to change because it is short.

5.8.8.4 Jakosky. **The project shall install and maintain a mission-planning and data communications workstation and communications link at each IDS Facility (IDS6)**.

5.8.8.5 Haberle. The following information is desired through the communication link to Ames to provide timely inputs to the GCM to aid in the design of mission sequences:

(1) Synoptic images from MOC. In general, these would consist *of* whole disk images taken on a daily basis over a week to several week period. They would have a resolution of about 10 km per line pair.

(2) Globally distributed condensation cloud climatology from TES and MOC. These would consist of reduced and multi-instrument integrated values of condensation cloud probability over a month's time span as a function of latitude. In addition values of cloud composition, optical depth, mean particle size, and amount of condensate would also be given. This information, in combination with the dust distribution would define the radiative forcing for the GCM simulations.

Second graphical outputs from GCM runs made during the mapping orbit phase of the mission will be provided through the communication link to the project office, experimenters, and other IDSs, to aid in mission planning.

6. PREFLIGHT TEST AND CALIBRATION

6.1 PREFLIGHT TEST CONSIDERATIONS

Preflight calibration requirements are described in detail in various individual experiment documents, e.g., investigation calibration requirements document, ICDs and integration and test plans. Consequently this section does not contain requirements. Section 6 is intended only to indicate special handling considerations following instrument delivery to the spacecraft contractor that will be the subject of the nominal implementation documents.

6.1.1 Deleted

6.1.2 Magnetometer (MAG)

In order to establish a high level of confidence in the instrument's ability to withstand the launch stresses and space environment throughout the Mars Global Surveyor mission, a comprehensive instrument qualification and acceptance test plan ("Performance Assurance Plan") will be implemented, as presented in detail in the Mars Global Surveyor Magnetic Field Experiment Implementation Plan.

The following requirements apply to the completed instrument package after delivery to JPL/spacecraft contractor-

(1) Subsystem test:

After delivery of the instrument to JPL/spacecraft contractor and prior to integration into the spacecraft, a functional test should be performed utilizing the experimenter provided Ground Support Equipment. In general, mu-metal fluxtanks, similar to those utilized for the Galileo and Voyager magnetic field experiments, will be required to attenuate the Earth's field and allow instrument and compatibility testing over the entire dynamic | range of the experiment. If available, the Voyager/Galileo fluxtanks can be I used without modification.

There are no special environmental constraints or requirements associated with this test. A standard clean laboratory environment, with humidity controlled to approximately 50+1Q% and electrostatic protection are acceptable. Caution should be exercised so as not to expose the sensors to fields greater than 5 Gauss or magnetic particle contamination which might cause an unpredictable shift in zero-level calibration. A coil system inside the fluxtanks is further required to control the attenuated field. The Voyager/Galileo fluxtanks include these coil systems and would be acceptable. This functional performance test shall be performed prior to the initial or any subsequent reinstallation of the instrument on the spacecraft.

6.1.2.1 System tests

(1) Integration

During instrument integration tests, the integrity and functional performance of all electrical and mechanical interfaces should be verified with the exception of the ER experiment MCP high voltage and thermal motor performance (MAG38). High voltage to the ER experiment's microchannel plates (MCPs) will be disconnected during these test to prevent damage to the MCPs and replaced with a resistive termination to simulate MCP impedance. The thermal motor that runs the aperture closing mechanism to seal the MCPs from contamination will not be activated except as described below.

Integrity and functional performance of all mechanical interfaces shall be verified with the exception of the ER aperture closing mechanism. This mechanism will be verified separately. The ER aperture includes a cone time release mechanism and a thermal motor for temporary closing. Operation and performance of the ER aperture closing mechanism should be verified in a cryopumped vacuum to protect the MCPs from any organic contamination.

Functional performance of the complete sensor, including operation of the microchannel plates, will be verified after completion of environmental testing. A portable vacuum chamber will be supplied by the experimenter for these tests.

'Direct access cabling' is desired to verify the proper operation of the magnetic field experiment on the spacecraft, and also compatibility with the Payload Data System. The fluxgate sensors may be replaced by "sensor simulators" which only respond to the electrical stimuli provided by a portable stimulus unit. As in the case of the functional tests, fluxtanks and associated coil and control systems will be required to reduce the external field to a small value consistent with the instrument's full dynamic range.

The ER experiment will have a range of internal diagnostic tests to check the working operation of all its electronics.

(2) Electromagnetic Compatibility Tests

An electromagnetic compatibility test should be performed to determine if deleterious radiated or conducted interference to the MAG experiment is generated by the spacecraft and its subsystems (including other experiments). For the conducted interference portion of the test, fluxtanks should suffice to eliminate all but conducted interference. For the radiated interference portion of the test, pulling coils (Voyager/Galileo coils are acceptable) are desired.

These tests should be conducted in a relatively magnetic noise-free environment with the spacecraft as nearly flight configured as possible. This includes the solar arrays which should be fully extended to locate the sensors as closely as possible to the actual flight locations. The test will probably require at least a full working day and should be performed during nighttime hours to take advantage of both, the lowest possible levels of facility generated interference and the generally least active period of the Earth's geomagnetic field.

During some period prior to these tests, measurements should be made of the magnetic field and its gradients within the proposed site of the test. This pre-EMC test magnetic mapping of the area will be desired to determine the magnitude and geometry of the background field and to establish the suitability of the facility for the performance of EMC tests. Acceptance criteria for the facilities are:

(1) that there are no large field gradients (>25 nT/ft) within the area in which the spacecraft and facility magnetometers are located;

(2) that the facility 60-Hz field is less than 15 nT peak-to-peak within the test area; and

(3) that transients in the field from all external, non-spacecraft sources, are less than 0.5 nT in magnitude.

To meet these requirements it will be necessary that the test area be free of extraneous equipment, furniture, etc.; that support equipment for the rest be located in a separate area connected to the test area by cabling: that electrical machinery within and nearby the vicinity of the facility be shut down; and that pedestrian and vehicular traffic within a radius of 150 ft. of the experiment sensors be controlled and restricted by the test director. It is of great importance to the MAG experiment to establish after final spacecraft assembly into flight configuration, that no spacecraft generated interference has either newly developed or gone undetected. This would degrade the correct operation of the magnetometer experiment as a highly sensitive detector of weak magnetic fields.

6.1.2.2 Miscellaneous. As part of the magnetics control program, all structures and any mounted sensors associated either with spacecraft systems or experiments, located in the immediate vicinity of the sensors, should be magnetically mapped and their net effect certified not to produce a magnetic field larger than 0.1 nT at either sensor location.

Sensor mounting surface alignment verification tests will be necessary to verify compliance with the alignment specifications described in this document.

6.1.3 Mars Orbiter Camera (MOC)

An internal calibration requirements document will be generated by the MOC Experiment Representative. A resulting calibration plan will be developed as described in the MOC Experiment Implementation Plan.

The MOC Ground Support Equipment and optical stimulus should be used ;n system test at the spacecraft contractor. Access for the optical stimulus to the MOC while the instrument is mounted on the spacecraft is desired for this testing.

Based on a 10% limit in throughput reduction and absolute accuracy degradation, the MOC contamination constraints are as follows:

Areal obscuration by particulates	3%
Molecular contaminants deposition thickness	500 Å
Purge (from launch to TOS separation, continuous)	19.5 scc/s
Cover (non-flight)	On at all times except when the instrument is tested with its stimulus

(1) Purge prevents virtually all vapor phase deposition of molecular contaminants (including oil) on MOC optics.

(2) Purge prevents penetration of the NA aperture by oil droplets 1 mm in diameter or smaller, moving at 6 m/s or slower.

(3) A coating of up to 500 Å thickness and index of refraction of ~1.45 (like, for instance, oil) on the MOC NA optics produces a change in reflectance of less than 1%, averaged over the bandpass of interest.

(4) The radiometric performance of the MOC NA will be degraded to 10% absolute by a 3-4% area coverage of particulates.

6.1.4 Deleted

6.1.5 Mars Orbiter Laser Altimeter (MOLA)

Preflight tests will be conducted at the GSFC, at the spacecraft contractor's plant, and at the launch facility. In order to gain a high level of confidence in the Mars Global Surveyor Laser Altimeter's ability to withstand the launch stresses and space environment throughout the Mars Global Surveyor mission and establish the MOLA's ability to perform as required, a comprehensive instrument qualification and acceptance test plan and calibration plan will be implemented at the GSFC's facility. Details on the above plans will be presented in the Mars Global Surveyor Laser Altimeter implementation plan.

The following requirements apply to the Mars Global Surveyor Laser Altimeter after it has been delivered to the spacecraft integration facility.

6.1.5.1 Subsystem Test. After delivery of the MOLA to the spacecraft integrator and prior to integration into the spacecraft, a functional test should be performed utilizing the experimenter-provided bench checkout equipment (BCE).

There are no special environmental constraints or requirements associated with this test. A standard clean laboratory environment with humidity controlled to approximately 50% +/- 10% and electrostatic protection is acceptable. The laboratory must provide space and power for the BCE and the MOLA. The laboratory should not contain high levels of RF which might interfere with the MOLA tests.

6.1.5.2 System Tests.

6.1.5.2.1 Integration. Checkout of both sides of the interface for adherence to the ICD should be performed before the instrument is integrated.

Integration tests will verify all of the Mars Global Surveyor Laser Altimeter to spacecraft interfaces. They will verify that the Mars Global Surveyor Laser Altimeter functions properly when interfaced to the spacecraft. All command and command sequences will be exercised to verify proper Mars Global Surveyor Laser Altimeter operation.

As part of the integration testing, the functional test in 6.1.5.1 will be repeated and compared to the baseline.

Full checkout of interfaces is required.

Direct access cabling between the BCE to the target assembly is necessary to verify proper operation of the instrument on the spacecraft and compatibility with the flight data system. This test will use the BCE together with the target assembly and a cooling plate attached to the instrument.

6.1.5.2.2 Electromagnetic Compatibility Tests. **An electromagnetic compatibility test should be performed** to determine if deleterious radiated or conducted interference to the experiment is generated by the spacecraft and its subsystems. Requirements for this test are TBD and will be included in the project EMI/EMC control plan.

6.1.5.2.3 Functional Tests. After each major spacecraft environmental test (acoustics, vibration, etc.), a functional test of the Mars Global Surveyor Laser Altimeter should be conduct to verify its proper operation and isolate any effects due to environmental testing.

In general, these tests are abbreviated versions of the initial functional test performed during experiment integration and can be completed in less than 20 minutes assuming that BCE is available.

6.1.5.2.4 Thermal Vacuum/Balance Tests. As part of the spacecraft environmental test, thermal vacuum/balance tests should be conducted to simulate as near as possible actual operation of the Mars Global Surveyor Laser Altimeter during the missions. Performance tests will be run on the Mars Global Surveyor Laser Altimeter at various points during the thermal vacuum tests. It is expected that a great deal of data will be generated and collected during this test. The BCE will provide the simulated input into the MOLA. Extensive data analysis will be performed on data collected through the spacecraft data system. Performance of the Mars Global Surveyor Laser Altimeter and its thermal control system will be evaluated via this test. Special command sequences will be defined for this test. Performance data will be compared to data obtained at the sensor contractor's plant.

After thermal vacuum tests when the spacecraft has been removed from the chamber, the functional test of 6.1.5.1 will again be conducted and evaluated.

6.1.5.3 Removal and Recalibration Requirements. In the event the MOLA instrument is removed from the spacecraft, abbreviated integration and functional tests will be performed for recertification.

6.1.5.4 Launch Facility Checkout. A complete functional test (using BCE) is desired where possible. At least one before integration on the launch vehicle is desired to assess possible shipping damage. Where a full functional test is not possible, only a simple go/no-go or minimum aliveness test will be performed. As a minimum, the closed loop operation of the calibrate mode will be used. An alignment check is desired.

6.1.6 Radio Science (RS)

Test and calibration data from the Mars Global Surveyor Telecommunications System (including the Radio Frequency Subsystem and the Antenna Subsystem) and from the Radio Science and Tracking Systems of the DSN are listed below. Support is needed from the JPL Verification and Test Facility (formerly CTA21) conducting some of these tests (TBD).

(1) Doppler Phase Stability Test

Phase Stability tests are desired over the relevant ranges of:

(a) Operating temperatures;

(b) Predicted received carrier signal strength,

(c) Telecommunications operation modes;

(d) Integration time (TBD).

(2) Range Calibration Tests

TBD

(3) Ultrastable Oscillator Phase Stability Tests

The Ultrastable Oscillator (USO) frequency stability tests should be performed over the relevant ranges of:

(a) Operating temperatures;

(b) Expected radiation environment;

(c) Telecommunication operating modes;

(d) Time duration of events.

The Ultrastable Oscillator shall meet the following requirements on frequency stability:

$\Delta f/f <$ TBD for 0.1-second integration intervals;

$\Delta f/f < 1 \times 10^{-13}$ for l-second integration intervals;

$\Delta f/f \sim 1 \times 10^{-13}$ for 10-second integration intervals;

$\Delta f/f < 1 \times 10^{-13}$ for 100-second integration intervals;

$\Delta f/f <$ TBD for 1000-second integration intervals.

The phase noise of the USO shall be less than or equal to TBD dBc per Hz for frequencies less than TBD Hz.

(4) Fractional Frequency Stability

The fractional frequency stability ($\Delta f/f$) of the signal generated by both transponders should be measured pre-launch for a range of integration times from TBD seconds to TBD seconds. This stability should be characterized by its Allan variance which shall be measured to a precision of 5%.

(5) Downlink Antenna Power Profile

The radiation pattern of the spacecraft HGA should be characterized before launch through measurements of the amplitude and phase of the emitted radiation over the main lobe and the first circular side lobe. Measurements shall be obtained for both the principal and the orthogonal polarizations over a two-dimensional grid with sample spacing of 30° in clock angle and one tenth of the beamwidth (boresight to first null) in cone angle. Amplitude measurements shall have a relative accuracy of 0.1 dB and an absolute accuracy of 1 dB. Phase measurements shall have an accuracy of 0.01 radian.

(6) End-to-end Radiometric Requirements

This section states the end-to-end radiometric requirements placed on the Mars Global Surveyor Spacecraft and the ground system as a whole. Also listed are the portions of the requirements which are allocated to the DSN and the portions allocated to the Mars Global Surveyor Spacecraft.

(a) Absolute frequency of spacecraft RF carrier.

The ability to determine the absolute frequency of the received S-band carrier using an integration period of TBD seconds.

Total requirement	TBD
DSN allocation	TBD
Spacecraft allocation	N/A

(b) Doppler phase stability.

The error contained in Doppler measurements with an integration time of TBD hours.

Total requirement	TBD
DSN allocation	TBD
Spacecraft allocation	TBD

(c) Received signal amplitude calibration.

The absolute error in measurements of the received spacecraft carrier amplitude.

Total requirement	TBD
DSN allocation	TBD
Spacecraft allocation	N/A

(d) Received signal amplitude measurement precision.

The error in measurements of changes in the received spacecraft carrier amplitude. This specification applies for changes occurring in less than a TBD minute period, with an averaging time per measurement less than or equal to TBD seconds, and for any two measurements within a 10-dB range.

Total requirement	TBD
DSN allocation	TBD
Spacecraft allocation	N/A

6.1.7 Thermal Emission Spectrometer (TES)

6.1.7.1 Calibration. The TES instrument will be radiometrically, spectrally and spatially calibrated prior to delivery. Three categories of calibration requirements are considered; absolute accuracy of all three bands (spectrometer, reflectance, and thermal bolometric), relative accuracy of spectral measurements within the spectrometer, and calibration stability over the lifetime of the instrument. The instrument will be calibrated within specification over a operating temperature range of +15+25 C, and will be tested to operate in a known state over a temperature range of +15+40 C.

6.1.7.1.l Radiometric Calibration (Thermal). The spectrometer and thermal bolometric channels will be calibrated in a thermal/vacuum chamber using two blackbody sources. One, held at liquid nitrogen temperature, will represent space and the other, variable temperature over the range 130 to 310K will represent the full range of expected planet temperatures. The temperature of the blackbodies will be designed to have an emissivity of greater than 0.995 over the spectral range of 6 to 50 microns and the resolution of the temperature measurement will be 0.05°C or better. The calibration sequence will be repeated for instrument temperatures over the operating temperature range of +15C+50C.

6.1.7.1.2 Radiometric Calibration (Visible). The solar reflectance channels will be calibrated using filament lamps traceable to NBS and a diffuser plate with known bi-directional reflectance distribution function (BRDF) properties.

Distance from the lamps to the plate will be used to vary the radiance over the expected dynamic range. The absolute accuracy of this calibration will be better than 5%. This test will also be conducted in a thermal vacuum chamber over the temperature range +15C+50C.

6.1.7.1.3 Spectral Calibration. Spectral calibration of the spectrometer will be conducted in either a vacuum or nitrogen purged chamber to minimize atmospheric absorption A monochrometer to precision of 2% and a wavenumber accuracy of ±5 wavenumbers. Alternatively, the overall spectral response of the instrument can be determined while viewing the cold blackbody during calibration. Relative spectral calibration of the solar reflectance channels will be accomplished in a similar fashion using a monochromatic source. Relative spectral calibration of the thermal bolometric channels will be accomplished with a combination of blackbodies and selectively transmitting optical materials.

6.1.7.1.4 Spatial Calibration. The instantaneous fields of view (IFOV) of the TES will be measured prior to delivery by means of a collimator and optically chopped quasi-point sources for the near field and extended targets for the far field and out of field contributions. The relative spatial response and centroid of each detector IFOV will be determined with a spatial accuracy of 0.5 mrad and an amplitude accuracy of 1% out to a radius of three IFOVs.

6.1.7.2 Handling Requirements. The following handling requirements must be met for the TES instrument.

(1) The TES should be properly bagged and placed in the TES carrying case for storage and transport in uncontrolled environments.

(2) The TES should be mounted on the TES handling fixture (when not in the carrying case) whenever practical during operation, temporary storage, and facility transport.

(3) The TES should not be exposed to relative humidities exceeding 55%.

(4) The TES should not be operated during thermal vacuum testing when the pressure is between atmospheric pressure and 5 x 10^{-5} torr.

(5) The TES should not be pointed such that the TES optical axis is less than 10° from the Sun line.

(6) The TES should not be subjected to temperatures less than TBD °C, nor to temperature change rates exceeding 2°C per minute.

(7) The TES should receive purge gas starting at spacecraft assembly until TBD minutes after launch vehicle sealing.

6.1.7.3 Test Requirements. In order to verify the instrument performance in the expected space environment, a comprehensive instrument qualification, test, and calibration plan will be implemented, as described in detail in the Thermal Emission Spectrometer Experiment Implementation Plan. This plan will be performed prior to delivery of the proto-flight instrument to JPL. The following requirements apply to the instrument test and calibration procedures from instrument acceptance through launch.

The following test procedures will be conducted following delivery of the TES instrument to RCA and prior to launch.

6.1.7.4 Subsystem Test. The following tests/calibrations will be performed by SBRC prior to delivery, using the TES Interface and Control Unit (TICU) and such other equipment as indicated below:

(1) Field of view including MTF, EDF and alignment-external collimator

(2) Scattered light response-external collimator

(3) Spectral response-monochromator and special sources

(4) Integrated Spectral out-of-band response (part of 3 above)

(5) Radiometric calibration. Signal to noise ratio Calibrator Unit (CU) and calibrator Control Unit (CCU) in thermal vacuum chamber

(6) Gain and linearity. Electronics measured separately; system linearity measured during radiometric calibration

(7) Aliveness test performed with the TICU and Stimulus Unit (SU). This test is the minimum test that checks the general functionality of the TES.

Following Flight Acceptance (FA) testing, tests 1, 4 and 5 as a minimum will be performed.

6.1.7.5 Electrical Performance Evaluation Test. This test will be performed at the spacecraft contractor immediately upon arrival of the TES instrument at the spacecraft contractor's facility. This test will be performed at room temperature using the TICU and SU with TES instrument under continuous dry nitrogen purge.

6.1.7.6 Payload Integration with PDS. The payload system integration tests will consist of TDB tests to be performed using the integrated payload and the PDS at the spacecraft contractor's facility. The TES performance during these tests will be determined using the source packet information transmitted directly to the TES BCE. These data will be analyzed using TES BCE. The TES instrument must be under continuous dry nitrogen purge during all of these tests.

6.1.7.7 Spacecraft System Tests. After delivery of the instrument to the spacecraft contractor and integration onto the payload system, spacecraft system tests will be performed. These tests will consist of:

(1) Electrical Performance Evaluation Tests (EPET).

(2) Initial Power and Turn on Test.

(3) Spacecraft Electrical Performance Evaluation Test (SEPET).

(4) Thermal Vacuum Tests.

(a) Launch Simulation.

(b) Thermal Vacuum (SEPET).

(c) Calibration Check

(5) Optical Alignment

(6) Vibration Tests

(7) Post-vibration Test

(8) Final SEPET

A full EMI test must be performed during the SEPET testing to determine any interference produced by any other MGS instruments. A full EMI test must be performed during the SEPET testing to determine any interference produced by any MGS instruments. This test must be performed with all subsystems on and in their most active dynamical and electrical states. Of particular importance will be the evaluation of the microphonics produced by all other subsystems. A complete log of the time history of all subsystem activity during these tests, together with the data tapes from these tests, should be provided to the TES team within one week of acquisition of the test data.

During the thermal vacuum SEPET test, the TES instrument will be tested for instrument performance using hot and cold blackbody stimuli provided as part of the TES BCE. These data will be used to determine the science performance of the TES instrument, including stray radiation effects produced by the spacecraft and payload.

During each of these tests, the TES performance will be determined using the source packet information transmitted to the TES BCE. Specific housekeeping health and welfare data will be transmitted to the spacecraft contractor test computer for instrument health analysis

Stimuli for determining the TES performance will be operated during these tests using TES BCE. The TES instrument should be under continuous dry nitrogen purge during all of these tests.

6.1.7.8 Removal and Re calibration Requirements. The instrument should not be removed from the spacecraft unless out-of-tolerance performance is observed during EPET or SEPET tests. No scheduled recalibration is planned.

6.1.7.9 KSC Checkout. Both the EPET and ambient SEPET tests can be performed at KSC. The instrument will be under dry nitrogen purge through the launch phase of the MGS mission.

7. SCIENCE ANALYSIS

This section deals with the activities of the MGS Project Science Group (PSG) during the flight of the spacecraft. The roles of each experiment team at their home institution in mission planning and science analysis may not be completely defined until after launch. However, the following paragraphs should be useful towards sizing the facilities, schedules and support personnel for mission operations.

7.1 JPL SUPPORT

7.1.1 Deleted

7.1.2 Magnetometer (MAG)

A basic level of support from JPL is required to conduct science data analysis during the cruise, drift orbit and mapping orbit phases of the mission. **Predict SPICE files are required at least 60 days in advance of major anticipated mission phases or changes in trajectory, orbit or spacecraft attitude (see MAG 33). Updated, standard SPICE files are required whenever the orbit/trajectory parameters, as predicted by the current SPICE, do not need the accuracy criteria stated elsewhere in this document (MAG32)** and will be determined by how fast the mapping orbit elements and spacecraft attitude evolve with time. Mission operations coordination, command loads, instrument interaction/conflict resolution, etc. are expected to be handled by the MGS Project and the PSG. Real time data acquisition support is desired for initial instrument turn-on and emergencies.

A fundamental driver in terms of science analysis is the type of workstation computer selected for MGS. Minimum storage and memory capacities are 500 Mbytes respectively. The data communications facility should be able to support a rate of 9600 baud as a minimum, with an effective information transfer rate of better than 4800 baud. Provisions should be made for data retransmission of 100% of acquired data. It is assumed that all software support packages associated with the workstation, i.e., communications, SEDR kernel processing, SFDU protocol support, science planning and reporting, etc., will be provided by JPL to the experimenters. Maintenance of the workstation is also assumed to be the responsibility of JPL including

software licenses and their upgrades. Common procurements of commercial database handling software, high level languages and signal/data processing programs is highly desired to reduce costs.

7.1.3 Mars Orbiter Camera (MOC)

The Project/JPL shall provide the MOC with the following:

(1) **Personnel: The Project/JPL shall provide support (partial salary support, office, travel, and operations support) for the MOC Experiment Representative (MOC24).**

(2) **Equipment: The Project/JPL shall provide a microcomputer workstation for uplink/downlink activities (see paragraph 7.2), including maintenance support, and one or more high-baud-rate communication lines (with support) to the MOC Operations Facility (MOC25).**

(3) **Other: The Project/JPL shall provide support for all quick-look analyses, facilities, offices, and data products required by the Project and/or NASA in support of activities associated with Public Information. Public Affairs, and press conferences (MOC26). The Project/JPL shall provide support for the publication of the initial and final reports of the MOC scientific investigation (MOC27). MOC requirements on the Project/JPL for data delivery are discussed in paragraph 5.4.3.1.**

7.1.4 Deleted

7.1.5 Mars Orbiter Laser Altimeter (MOLA)

In order for the MOLA investigation team to perform its data processing tasks, **the following requirements are placed on the Project:**

(1) **Provide the data link hardware and software for data communication between the Project Data Base (PDB) and the MOLA PI (MOLA10).**

(2) **Provide the hardware and software for creating command sequences which direct the spacecraft CDU/PDS to issue commands to the MOLA (MOLA11).**

(3) **Provide the capability for transferring data between the Project-supplied SOPC and a GSFC computer used for reduced data record processing (MOLA12).**

(4) **Provide the telemetered MOLA EDR, SPICE information (e.g., SPICE kernels) and software tools for evaluation this information, and spacecraft engineering data (MOLA13).**

(5) **Provide a database of other instruments' data and the necessary software for accessing this data (subject to inter-experiment negotiation) (MOLA14).**

(6) **Provide for the transmission of properly documented reduced MOLA data to an archive (MOLA16).**

(7) **Assume responsibility for providing a database for MOLA reduced data products to other investigators (MOLA17).**

(8) **Provide an end-to-end Mission Operations System (MOS) test prior to the mapping mission that allows exercise of the Project-provided SOPC (MOLA18). Provide it prior to launch (goal).**

(9) **Provide for full commanding of the MOLA at the spacecraft contractor facility after payload integration (MOLA21).**

(10) **Provide the planning aids as stated in Section 5.5.5 (see MOLA7-9).**

(11) **Provide a log of momentum wheel dumps (MOLA19).**

(12) **Provide time tags and positions for all Earth occultation egress and ingress events (MOLA20).**

7.1.6 Radio Science (RS)

The Radio Science Team will require routine monitoring of DSN Tracking and Radio Science System performance (RS58).

7.1.7 Thermal Emission Spectrometer (TES)

The support required form JPL during the MGS Project will include the following:

(1) **Experiment Representative support, including salary, office space, operations, and travel to attend TES Team Meetings and other designated meetings (TES20).**

(2) **Instrument Engineer support, including salary, office space, operations, and travel to attend TES Team Meetings, spacecraft interface meetings, engineering reviews at Santa Barbara Research Center, and other designated meetings (TES21).**

(3) **Direct access of the Project Database at JPL (TES22)**.

7.1.8 Interdisciplinary Science (IDS)

7.1.8.1 Arvidson.

7.1.8.1.1 Instrument teams should reduce the data to geophysical units that are time and location (on Mars) tagged. Enough ancillary information should be included to be able to reconstruct the radiometric and geometric processing histories.

7.1.8.1.2 The reduced data should be available on a regular basis, either continuously or in predefined chunks. The chunks should be defined as delivered on the basis of the selected mapping cycle (e.g., 3 sols).

7.1.8.1.3 Reduced data should also have associated documentation on why the particular data were acquired (e.g., special sequence tracking dust storm, etc.).

7.1.8.1.4 Reduced data on surface properties (in geophysical units) should be gridded to a sinusoidal equal area projection, using a grid spacing determined by the data spatial resolution. These digital maps should be available on a regular basis, preferably via electronic mail.

7.1.8.1.5 Information about the reduced data should always be accessible electronically. **The system should support remote queries, orders and delivery of appropriate data for the PSG (IDS9).**

7.1.8.1.6 **The Project should distribute in digital form a global Viking Orbiter digital image mosaic for use in analyses of Mars Global Surveyor data (IDS9)**. The mosaic should be in sinusoidal equal area projection with highest feasible spatial resolution.

7.1.8.1.7 **The Project should be able to accept into the Project Data Base highly derived digital maps that show, for example, the abundance of particular weathering products (IDS10)**. Information about these highly derived data sets should be available as defined in 7.1.8.1.5.

7.1.8.1.8 The great amount of interaction needed to complete the science objectives outlined in previous sections demands efficient mechanisms for sharing information and data among members of the Mars Global Surveyor science community. **Thus, a modern electronic network that allows direct access to TL, PI, IDS, and Project personnel should be implemented (IDS11).** Direct access to the Project Data Base may not meet this requirement.

7.1.8.1.9 Arvidson desires an office (desk, chair, cabinet, phone, secretarial support) for the time he plans to spend at JPL doing science and fulfilling his duties as IDS for Data and Archiving. He plans on being in residence several working days per month.

7.1.8.2 Carr. As indicated under 5.3.9, science analysis must occur concurrently with the mission in order to establish the focus of subsequent observations. To facilitate this, **the Project shall provide access to evolving standard MGS data bases for each instrument in such a manner that cross correlation between data from different instruments can be effected (IDS12). An office shall be provided in the operations support area (IDS13). The operations support area shall have appropriate facilities for accessing the different data base and for displaying data acquired to date by all instruments consistent with SOPC requirements (IDS14).** The support area should also include large tables for cartographic layout.

7.1.8.3 Ingersoll. To be determined.

7.1.8.4 Jakosky. The project shall provide a forum through the PSG for negotiation with the instrument PIs and TLs for access by the IDSs to data **from each instrument on a timely basis, and for participation by the IDSs in appropriate instrumental investigations (IDS15)**. The PSG shall negotiate a uniform plan for sharing of data and analysis.

7.1.8.5 Haberle. The best available data records from various experiments will be provided in a timely fashion to meet major scientific objectives of this investigation. The requested information includes:

(1) MOC.

(a) Synoptic images.

(b) Wind speeds.

(2) MOLA. Surface topography. Optimally this would consist of complete global coverage with a grid size of 1° of latitude by 1° of longitude.

(3) TES. Optical constants of suspended dust particles as a function of space and time.

(4) TES and MOC. A climatology of local dust storms and condensation clouds. This climatology consists of monthly averaged values of the occurrence frequency, altitude, mean particle size, composition, and optical depth of these clouds as a function of latitude, longitude, and seasonal date.

7.2 COMPUTER FACILITIES/WORKSTATION

A summary of the Project supplied workstation requirements is given in Table 7-1.

Table 7-1. Workstation Requirements

FUNCTIONS

- o Planning
- o Command Transmission
- o Performance Verification
- o Data Base Retrieval
- o Data Base/Archival Input
- o Data Processing

CONFIGURATION

- o Compatibility
  - o VAX: 750, 780, 785 and 790
  - o Micro VAX-II
  - o Sun 3/160
- o Operation Base
  - o VMS
  - o UNIX
- o Language
  - o FORTRAN, C, Pascal
- o Storage
  - o 100 Mb-3 Gbyte
- o Memory (Speed)
  - o 2-10 Mb (>10 MHz)
- o Link
  - o 9.6-56 kb/s
- o Miscellaneous
  - o Tape Drive, 1/2 inch. 6250 bpi
  - o Displays 1024^2 x 8 bits
  - o Hard copy backup
  - o Color display
  - o CD-ROM Reader

7.2.2 Magnetometer (MAG)

The magnetic field investigation has baselined a combined capability for science data analysis comprised of our existing VAX 11/790 plus the facilities provided by the workstation computer. The minimum requirements for the workstation (SOPC) have already been given in the previous paragraph. No additional procurements of data processing equipment are anticipated/ planned.

ER data will be analyzed at UCB and CESR. Quick-look data will be provided by the workstation at GSFC (in raw, packet form) over existing networks to UCB. In addition, GSFC will provide occasional dumps of all magnetometer and ER data on tapes or optical discs to UCB and CESR. Data will be analyzed Wit}l existing facilities at UCB (VAX 11/750), possibly augmented as necessary to accomplish the ER data analysis objectives.

7.2.3 Mars Orbiter Camera (MOC)

The MOC investigation requires several different microcomputer systems: two Ground Support Equipment (GSE)/Bench Checkout Equipment (BCE) controllers, Flight Software (FS) and Ground Data System (GDS) development systems, Mission Science Operations and Planning Computer (SOPC) workstation, and Science Analysis and Data Archiving Computers (SADAC).

The GSE/BCE controllers are microcomputers that simulate commands to the MOC on-board processors and that control the MOC Test Stimulus. One of the GSE/BCE systems is deliverable to the Project for Instrument Integration and Testing. This system shall be returned to the MOC 45 days after launch. The other will be used for Instrument calibration, and will be maintained at the California Institute of Technology.

Flight software will be developed and tested on the Flight Software Development Test Bed. The test bed consists of two VAX II microcomputer workstations and their associated peripherals and a MOC electronics simulator consisting of a NS32C016 microprocessor, a 12 MB RAM buffers and associated electronics all linked by a local area network.

The GDS development system is used to develop mission planning and instrument operation and control software. It consists of Sun 3 and 4 microcomputer workstations and their associated peripherals, connected by a local area network.

The SOPC, to be provided by the Space Flight Operations Center through the Project, is used for mission planning and operations, distribution of data, Project communication, and some data analysis, in particular that dealing with instrument status, health, and performance.

The SADAC will be procured and established at the MOC Operations Facility. They will be used primarily for science data analysis and production of reduced data records, and for MOC-specific operational activities not covered by the SOPC. They will be linked to the SPOC and act as backup to that computer during downtime associated with scheduled maintenance and hardware failures. Values listed in paragraph 5.4.3, and those in the following list, were used in estimating the processing and storage capability requirements for the SADAC:

(1) Image size (Compressed values in parentheses):

Minimum image size	4 MB (1.3 MB)
Maximum image size	36 MB (12 MB)
Average image size	12 MB (4 MB)

(2) Average processing times (assuming VAX II capabilities):

Unpacking time	3 minutes
Decompression time	12 minutes
Geometric rectification time	120 minutes
Re-compression time	15 minutes
Contrast enhancement time	15 minutes
Spatial filter time	45 minutes
Processing time per frame	3.5 hr per image
Processing time per day	46 MB/day ÷ 4 MB x 3.5 hr 40 hr/day
Peak daily processing time	125 MB/day ÷ 4 MB x 3.5 hr 109 hr/day

On the basis of the above list, each SADAC must have specific attributes that include:

(1) Computational power- the processor must include and be able to address a large random access memory (≥24 MB), at high computational speeds (≥10 MHz), in order to decompress and process the images;

(2) Internal I/O Characteristics- images represent significant problems to I/O, owing to the large volumes of data that must be moved from place to place. Bandwidth is the most crucial concern: it must exceed 1.8 Mb/s, and 2.5 MB/s is preferred. A 32-bit data transfer bus is required.

(3) External I/O Characteristics- in order to transfer data between MOC processors within the MOC Operations Facility, between the Project and the MOC Operations Facility, and between MOC Operations Facility and the home institutions of the Co-Investigators, several forms of I/O capabilities must be resident in the SADAC. Computer compatible tape (1/2 inch), asynchronous and synchronous communications ports, and local area and remote networking (Ethernet, etc.) capabilities are required.

(4) Mass Storage- the MOC will generate data at an average rate of 46 MB/day. This will decompress to an average of about 230 MB/day, depending on compression schemes. On-line access to a large part of the data set is extremely important for science analysis and mission planning. Minimum requirements for on-line volatile storage are ≥3 GB of magnetic disk storage (≥500 MB/drive) and 50 GB of WORM storage.

(5) Display- once decompressed, MOC data are in image format. MOC will produce hardcopy of only a very select number of images. However, every image must be visually inspected and analyzed. The SADAC will be the primary means of visually examining and studying the MOC data. Display of at least 1024e2 8-bit pixels is required; 2048e2 8-bit pixels is highly desirable.

The requirements for the SOPC and SADAC are, for the most part, similar, although the Project cannot guarantee complete hardware or functional compatibility. These requirements lead to the following configuration specifications.

The MOC SADAC shall consist of more than one 32-bit microprocessor with 24 MB of RAM each, floating point accelerators, and at least 3.0 GB of multiple write, multiple read (MWMR) disk storage. 50 GB of on-line write once read many times (WORM) mass storage will also be required. Two 1/2-inch tape drive with 6250 bpi, 125 ips capabilities, is required to provide the ability to transport data and software. A high resolution graphics capability (at least 1024^2 8-bits deep required; 2048^2 8-bits preferred), and hardware and software supporting menus, windows, and mouse/keyboard user interface, are required. The UNIX operating system will be used to allow portability and compatibility with the software development systems, and support standardized programming in C and FORTRAN. All programs will be written in standardized programming languages (mostly C and FORTRAN). Communications capability will be available through RS-232C and Ethernet interfaces. Output will be through printers and other devices.

7.2.5 Mars Orbiter Laser Altimeter (MOLA)

The SOPC will be linked to the NASA Space and Earth Sciences Computing Center (NSAESCC) engineering computers both at GSFC and Wallops Flight Facility (WFF) at GSFC via magnetic tape.

The SOPC will be used for MOS functions (e.g., Project communications, command generation, data transfer, and packet decommutation. Quick-look health monitoring (HM) and low-level data processing (LDP) for the CEPDRs and EGDRs, will be dome primarily in the GSFC/HSVP (High Speed Vector Processor) within the NSAESCC. In addition, some engineering analysis and performance assessment (PA) may be performed in other computers at GSFC and WFF.

The workstation (SOPC) must be sized to handle retrieval of MOLA data products from the PDB and transmission of MOLA data products between the sequence generation, history logging, health monitoring, and calibration processing (see MOLA12-13). The operating system should support multi-users/multi-tasking, tree-structured files, and high-level languages, and should include I/O utilities, and a full-screen editor. Thus an operating system like UNIX is desired.

A UNIX operating system requires up to 1 Mbyte of memory (RAM) and up to 50 Mbytes of disk storage. An estimate of the amount of storage required for data can be made under the assumption that the SOPC must be able to handle a week's worth of data at a time. This requires 54 Mbyte for EDR (raw) data and 200 Mbyte for EPDR (processed profile) data. In addition, at least 100 Mbyte are required to transfer the gridded products.

SOPC usage is planned around an 8 hour day and a 5-day week. The following functions will be performed

1. Check PDB for messages and take any required action.

2. Verify that any commands which were to be sent to the MOLA were actually transmitted, and that the MOLA is in the proper operating mode.

3. Retrieve from the PDB any newly received MOLA data, SPICE information or orbit data.

4. Decommutate data, perform health/status checking, and reporting.

5. Update local database log to reflect newly received data.

6. Generate MOLA command sequences (if needed) for the next sequence cycle and transmit to the PDB. It is expected that a command dictionary, command generation software and orbit predict information will be provided.

7. Transmit to the PDB any processed data ready for archiving. Update local database log to reflect this transmission.

8. Provide any requested data for the MOLA Science Investigation Group.

9. Transmit data from the SOPC to the GSFC/SCF for production processing, and update local database log to reflect this activity.

10. To the extent possible, perform profile processing on the EDR. The SOPC will be linked to an in-house system that will conduct any profile processing for which the SOPC does not have sufficient resources.

MOLA suggests the following implementation of the SOPC:

l. 32-bit architecture

2. 4 Mbyte main memory

3. 600 Mbyte hard disk storage with dual controller

4. Multi-user/multi-tasking operating system such as UNIX

5. Hardware required for network connection to the PDB

6. Color graphics display, 760 x 612 pixels, 6 planes

7. Keyboard and mouse inputs

8. Printer (laser type for text and graphics hard copy)

9. Three available RS-232C interfaces

10. FORTRAN and C compilers, word processing software, database management software, communication software

11. Full documentation

12. Maintenance services

13. Dual magnetic tape unit (at least 1600 bpi, prefer 6250 bpi) or other appropriate backup system for disk and data transfer.

7.2.6 Radio Science (RS)

7.2.6.1 Work-Station Requirements. It is planned to use the project supplied workstation for routine operations including:

(1) Electronic communication;

(2) Coordination of sequencing requests and verification of command sequences;

(3) Real-time and near real-time monitoring of spacecraft t and ground radiometric performance;

(4) Transfer of data from Project Data Base to Radio Science Team investigators;

(5) Computationally-thin data reduction, display, and analysis tasks;

(6) Local area network terminal for use of investigator computation facilities for computationally intensive tasks and local data archives;

(7) Transfer of reduced data products from Radio Science Team investigators to the Project Data Base.

7.2.6.2 Processing Capabilities. For long range planning purposes in configuring local investigator systems it is assumed that the **Project workstations shall be compatible with the UNIX operating system and Ethernet TCP/IP** or other standard network protocols (i.e., not vendor restricted), **and will support program development and execution in 'C', Pascal, and FORTRAN languages (RS59)**.Graphics capabilities with hardcopy output will be needed to support both development and applications functions.

Radio Science investigations rely heavily on numerically intensive data reduction and analysis procedures so that each investigator will require access to general purpose computing facilities. For the gravity investigators this requirement includes access to and use of supercomputers.

The Radio Science Team includes members from several widely separated home institutions. Team member interfaces will be required for the following sites and purposes. The number of locations listed here reflects the need for access to the Project Data Base by each investigator at these sites.

Number	Site	Use
1	Stanford	i) Input and verification of command sequences for spacecraft and ground operations; ii) Access to and analysis of data on atmospheric structures iii) Communications within Radio Science Team; iv) Project-wide exchange of reduced data.
1	JPL	i) Access to data for gravity investigation; ii) Access to and analysis of data on atmospheric scintillations, iii) ear real-time monitoring of ground operations; iv) Communications within Radio Science Team; v) Project-wide exchange of reduced data; vi) Instrument health monitoring.
1	GSFC	i) Access to data for gravity investigation; ii) Communications within Radio Science Team; iii) Project-wide exchange of reduced data.

1	BGI/CNES	i) Access to data for gravity investigation; ii) Communications within Radio Science Team; iii) Project-wide exchange of reduced data.

For team operations, electronic access from Stanford and JPL to the Project data base will be required 24 hours per day over the active period in Martian orbit (RS60) and at TBD times otherwise. For other institutions, electronic access will be required between the hours of 0600 to 2400 LT, daily.

7.2.7 Thermal Emission Spectrometer (TES)

7.2.7.1 Hardware Requirements. The bulk of the data received on the ground will be in the form of spectral radiance. Any subtleties of calibration not accounted for on the spacecraft will be applied in ground processing. The spectrometer data are then analyzed in two major ways: geologic processing begins with the reduction to surface kinetic temperature and spectral emissivity; atmospheric processing uses the spectral radiance to extract temperature profiles, C°2 total pressure, H20 and ozone abundance, and dust and ice opacity and spectrum, as appropriate. When partial spectra are down-linked, some of these steps will be omitted. Geologic processing will consist of the determination of instantaneous energy balance and estimated one-point thermal inertia (using the radiometer data), mapping of spectral components, comparison of spectral emissivity with a spectral library, and component identification.

The computational requirements are to be able to process the maximum data rate expected at any point in the mission. Assuming all IFOVs operating for the entire orbit with full spectral resolution, a maximum of 6 spectra must be fully processed in 2 s. Assuming the maximum downlink rate, the data volume would be 1.6 x 103 bits/day. The nominal rate will be approximately 8.7 x 107 bits/day. A maximum of 260,000 spectra will be acquired each day; typical values will be 125,000 spectra per day. The standard processing of these spectra will include: (1) unpacking and decompression of downlinked source data; (2) reconversion of data to radiance; (3) reformatting; (4) quality checking; (5) detailed fit of blackbody curve to determine surface kinetic temperature; (6) determination of emissivity; (7) calculation of pointing geometry from SPICE kernels and integration of spectral radiance with geometry information; and (8) spatial resampling of spectral radiance values to a uniform grid. At a minimum, this analysis must be performed at a rate of 3 spectrum per s to keep up with the flow of data.

Additional data processing will include: (1) input/output overhead to transfer the data to and from the Project data base; (2) derivation of thermophysical properties; (3) determination of basic atmospheric properties; and (4) characterization of spectral properties using developed algorithms.

A computer facility will be developed that is capable of performing the standard data processing task using 50 percent of the available computer resources, thus providing a 100 percent margin for this effort. This facility will be staffed at a level of 10 shifts/week (80 hours/week), and operated unattended 88 hours per week. The 50 percent of the computer facility not dedicated to standard processing will be devoted to producing reduced data products, including mineralogic determinations mosaics, and derived parameters.

The data processing requirements to handle the data flow in real time will require the following computer system:

(1) One file server with 7.5 Gbytes of on-line storage and 6250 bpi tape drive. This system is scoped to handle the full TES data volume on line for one 57 day mapping cycle.

(2) Two CPUs to handle radiometric processing, spatial resampling, and science analysis. These CPUs must be capable of handling the 3 spectra per 2 s data flow rate.

(3) One Project-supplied workstation for uplink planning and communication and downlink communication both to and from the Project Database.

The data processing facility for major data calibration and reduction will be developed at the PI institution. Basic data processing will be done on this system and calibrated data will be distributed to the Co-Investigator institutions for detailed analysis in the specialties on their institutional computers. This distribution will be done in "real-time" through the Project Database. Subsequent distribution of validated data will use CD-ROM if available.

7.2.7.2 Software Requirements. **It is required that all software required to manipulate NAIF SPICE kernels and to support reconstruction in the full instrument pointing geometry will be provided by the MGS project (TES23).**

It is also required that the Project will supply all of the uplink planning hardware and software and the downlink communication software and hardware necessary to handle the estimated 56-kbps data transfer rates to and from the Project Database (TES24).

The ground data processing software will be developed in two stages. The first stage will develop the basic data handling and processing capability to acquire, format, calibrate, and display the output from the TES instrument. This capability will need to be developed prior to the first acquisition of test data from the flight instrument in order to facilitate test and checkout of the flight hardware prior to launch.

The second stage of ground software development will include the full capability to processes TES data in real time (1 spectrum per s), to decompress the data, to unpack the TES source frames, to perform full instrument health performance, and calibration functions, to generate full geometric information, to develop image cubes with associated geometry information, to perform geometric resampling to a standard grid, and to generate the science data products.

The software system to be developed for the data processing facility will conform to the standards being developed for the Planetary Data System, allowing wide distribution and ease in archiving. The software for thermal analysis is available (Kieffer, Christensen), a full package for geologic spectral analysis is available (Clark), a preliminary software package for atmospheric spectral analysis and temperature sounding is available at GSFC (Pearl), and an extensive software system for conversion of orbital results to global maps exists at Flagstaff (Kieffer). These software systems must be integrated and upgraded to provide the science analysis support to meet the investigation science requirements.

7.2.8 Interdisciplinary Sciences (IDS)

7.2.8.1 Arvidson.

7.2.8.1.1 **The Mars Global Surveyor data system should have a centralized Project Data Base containing raw data (see IDS 8-11).** Information about the data should be available, as outlined in the previous section. The Mars Global Surveyor science community should be networked to the Project Data Base with at least 9600 Baud links and preferably with 56 Kbaud links. As noted in the previous section, networking should also be implemented to allow efficient communications among the Mars Global Surveyor science community.

7.2.8.1.2 Local computational and data management capabilities at Washington University will be used to complete the defined tasks. Thus, for efficient use, the Project-supplied workstation will need to be interfaced to our VAX/VMS system. To the extent feasible the workstation should be compatible with such a system (VAX/VMS)(goal).

7.2.8.1.3 A common interface language should be used across all elements of the data system (goal). Common data delivery commands are an example of interface language requirements.

7.2.8.1.4 The workstation at user Home Institutions should be the primary way to conduct uplink planning, downlink monitoring, acquiring information about data, and ordering data. It should also be used to and access and deliver data to the extent data volumes allow cost-effective electronic transport. Since data reduction will be conducted largely on other systems, the workstation should be chosen for ease of interface with the common systems in place or planned for Mars Observer data reduction. Those systems are VAX-dominated

7.2.8.2 Carr. **A workstation will be required for access to the various mission generated data bases and comparing them to each other (see IDS16).** The detailed characteristics of the workstation are TBD. However, certain basic requirements should be met. The workstation should have access to the MGS database and be able to display planning aids such as the Viking digital image database, and previously acquired MGS data in some reduced form. The workstation should also have the capability of overlaying and registering different data sets, then using data sets from different instruments to characterize the surface on a pixel by pixel basis. Typical data sets to be used in this manner are the Viking 1:15,000,000 geologic map, and maps of the scattering properties of the surface produced by MORAR. **Access to SPICE data via the workstation will also be required, together with algorithms for computation of various SEDR parameters (see IDS16).**

7.2.8.3 Ingersoll. As far as hardware is concerned, I have a Micro-VAX-based system at Caltech that I plan to enlarge for the MGS project. Details of the interface with MO will have to be worked out.

7.2.8.4 Jakosky **This workstation shall have attributes to enable the following: (1) Communications link with the project database to be located at Jet Propulsion Laboratory (see IDS16).** This link shall be capable of transmitting data and data products in both directions between the project database and the workstation with no significant errors introduced and at a data rate sufficiently rapid for major fractions of the data to be transmitted. It is currently anticipated that a data link of about 9.6 kbaud and an error rate of less than 1 in 10^8 (protocol) will be adequate. (2) **Rapid (turnaround <30 min.) communications with other IDSs and with PIs and TLs through their workstations/PDB (IDS16). (3) Access to a digitized version of the Viking photomosaics, preferably in the format which is a high-pass filtered version (see IDS11)**, if possible, in a radiometrically corrected form. (4) **Two-way communications with my home-institution computer facility,** to enable data and data products to be transmitted for further analysis or for transmittal to the project database. (5) **On-line storage of some of the transmitted data**. It is anticipated that storage equivalent to 30 days' worth of observations will be adequate. (6) **Display of any on-line data or data product (IDS17)**, either by listing to a terminal screen, listing to a hard-copy printer, plotting to a terminal screen, imaging to a screen in either shaded or color display, or copying of text or plots (but not necessarily black and white or color images) from the screen to a hard-copy unit (goal). (7) **Display of the orbital**

information for any or all prior times during the mission (IDS18), including ground tracks and projected fields of view for each instrument when that instrument was in a data-taking mode. (8) **Display of orbital, ground track, and SPICE information as planned for the next 60 days (IDS19).** (9) **Display of the planned mode of operation for each instrument for the next 30 days if provided by PI in SPICE Kernel (IDS20).** (10) **Display of the ground track beneath the transmittal ray line of sight for radio occultations where the ray is beneath 50 km altitude for the tangent point being at the surface, for all previously occurring occultations, and for those planned for the next 60 days (IDS21).**

7.2.8.5 Haberle. A workstation and a high-speed link to JPL shall be provided at Ames. **Key attributes of the workstation should include:**

(1) **A high-speed link to JPL (IDS22)**.

(2) A minimum memory of 10 megawords (goal) and a desirable memory of 50 megawords (1 word = 64 bytes). Note that the minimum requirement corresponds to the number of words on a GCM tape for 10 simulated days.

(3) **A processing capability that is greater than that of a PC computer and optimally comparable to a MicroVAX (see IDS16)**. For efficiency of operation, it would be best if the workstation had stand-alone capability.

(4) **It is essential that the workstation be able to communicate effectively and easily with the Ames Space Science Division's VAX computer (IDS23)**. Currently, this VAX uses a VMS operating system, although it may switch to a UNIX system within the next several years.

(5) A graphical set of capabilities that will permit the quick display of data from the mission's database, of graphical output from the GCM, and the overlaying of several data sets.

(6) **The ability to search the mission's database to define available products and to efficiently obtain such a subset (see IDS16)**.

(7) **The Viking database map should also be available on CD ROMS and accessible to the workstation (see IDS5)**.

7.3 REDUCED DATA RECORD ARCHIVING

7.3.1 Deleted

7.3.2 Magnetometer (MAG)

Reduced data records will be produced as final EDR/SPICE records become available from the project mission operations facility. The estimated production time for reduced records after receipt of final data is 30 to 45 days, which is consistent with the desired 57-day mapping cycle period.

Production of reduced data records for the magnetics field investigation does not require any other instrument's data inputs; only spacecraft position and attitude data. Thus this effort can proceed in parallel with these activities and on a time base and delivery frequency commensurate with delivery of final SEDRs kernels or data. Correlative or interdisciplinary investigations that make use of multi-instrument data sets will be supported directly from the project data base. We plan to generate "immediate" (within (30 days) data sets with preliminary calibration parameters and reduced time resolution to support timely and "quick-look" analyses of the magnetic field data, with detailed data records deposited at a later date in the project database. The magnetic field data will be delivered in the form of annotated time series of the measured magnetic field components (corrected for spacecraft field effects) and derived quantities such as magnitude and RMS deviations over the averaging intervals. These data will be given in a coordinate system centered at Mars and rotating with the planet. If the planetary field is sufficiently strong and spacecraft effects negligible, a crustal magnetic anomaly map will be generated and deposited in the project database in digital form. It is anticipated that this effort could be accomplished, if possible, after the 10th mapping cycle.

The project supplied workstation will be used for a quick-look at the ER data and to monitor instrument health. Raw data will be transferred from the workstation to the VAX at UCB/SSL for production and analysis work, and to produce tapes of the raw data to send to our Co-Experimenters at CESR Toulouse. The combined magnetometer and ER data sets will be used to compute the planetary magnetic fields as a function of position for various absorption heights from 120 km to 200 km. Eventually these preliminary maps will be used to produce a map of the crustal remnant magnetization. A reduced data set will be returned to the project data base for use by other experimenters.

7.3.3 Mars Orbiter Camera (MOC)

MOC data transmitted to Earth will be highly compressed (by factors of 3 to 30 or more). Creation of multiple standard products would increase this expansion by additional factors of 2 to 4. Thus, the amount of RDR MOC could conceivably deliver could exceed 1×10^{13} bits. MOC will therefore be unable to deliver to the Project Data Base expanded Reduced Data Records. Rather, both the MOC EDR and RDR will be delivered to the Project Data Base in compressed format. EDR will include compressed images, preliminary geometric and radiometric calibration data, and the decompression algorithm(s). RDR will include only updates to the final geometric and radiometric calibration information. The archive will be entirely digital.

The only RDR to be produced in image format will be that acquired for daily global monitoring. These data will be fully calibrated with the latest available calibration at time of release and placed in a standard geometric projection.

7.3.4 Deleted

7.3.5 Mars Orbiter Laser Altimeter (MOLA)

The primary reduced data from this investigation will be derived from the MOLA experiment data record (EDR), together with a precision orbit derived from data supplied by the Radio Science investigation. The reduced data which will be returned to the project for archiving will be in two formats. The first format is profile data (see Table 7-2a). Both the experiment processed data record (EPDR) and the corrected experiment processed data record (CEPDR) will be in this format. The EPDR contains the nominal navigation-supplied orbit information, whereas the CEPDR contains the investigation-supplied precision orbit. The second format is gridded data (see Table 7-2b). The experiment gridded data records (EGDR) will be supplied in this format. Based on the orbit specified in Section 3.2.5, there will be products with grid spacings of 30 km, and 12 km. Each of these products (with the exception of the EPDR) may have multiple releases. In addition to the primary reduced data described above, the MOLA team will provide a set of experiment calibration data (ECD) derived from the internal calibration mode of the instrument.

Table 7-2a. Profile Data Frame (per second)

Parameter	Bytes	Units
Time tag	8	seconds
Rev. No.	4	count
Location	8	lat./lon.
Height of Orbit	8	meters
Mean Range	8	meters
Delta Ranges (20)	80	meters
Mean Elevation	8	meters
No. of Returns	4	count
S/C Attitude	12	mrad
Received Power 1 (20)	80	dB
Received Power 2 (20)	80	dB
Transmit Power (20)	80	dB
Background Power	4	dB
Filter Width (20)	20	filter no.
Peak amplitude (20)	80	dB
Quality	2	status
Housekeeping	8	volts
	494	

Table 7-2b. Gridded Data Element

Parameter	Bytes	Units
Mean Elevation	4	meters
Gradient	8	meters/kilometer
Reflectivity	4	percent
Standard Deviations	8	
No. Points	2	
Total	26	

Based on the data rate and structure outlined in Section 4.6.5, the EDR volume for one Martian year should be about 5 Gbytes. This translates to a EPDR volume of about 1.2 Gbyte for each 56-day mapping cycle, for a total volume of about 16 Gbyte by the end of mission. Each release of the CEPDR should also be about 1.2 Gbytes per mapping cycle. Each release of a 30 km or 12 km EGDR will have a volume of about 4 Mbyte, or 25 Mbyte, 100 Mbyte, respectively. Thus we anticipate a total archive volume of approximately 60 Gbyte.

The EPDR will be provided to the PDB as soon as the MOLA team completes verification. Multiple releases of the CEPDR and EGDRs will be provided as they are completed. In addition, limited amounts of preliminary data may be provided to the Project for use by other

Mars Global Surveyor investigation teams early in the mission. The final release for permanent archive will not be available until after the mapping phase ends.

The MOLA investigation will produce a precision orbit for use in producing the CEPDR and EGDRs. The accuracy of this orbit determination will improve during the mission. Each CEPDR and EGDR will contain the best orbit data available at the time it is processed. A final set of precision orbit data will be provided to the Project after the end of the mission.

The MOLA may provide useful data for some period during the quarantine phase. Currently, these data are considered to be for MOLA investigation team use and will not be formally processed into archival data records.

In summary, the MOLA-provided data products are:

1. EPDR (Experiment Processed Data Record)
2. CEPDR (Corrected Experiment Processed Data Record)
3. EGDR (Experiment Gridded Data Record)
4. Calibration data

The following data are required from the Project (see MOLA 7-9.28-29):

1. **MOLA EDR (Experimental Data Record)**
2. **SPICE Kernels**
3. **Orbit predicts**
4. **MOLA command log**
5. **All MOC and TES frame time tags and locations**
6. **Momentum wheel dump log**
7. **Occultation times**
8. **Mars digital terrain model and digital image model (MOLA22)**
9. **Selected MOC and TES data**
10. **Gravity field derived by the Radio Science investigation (MOLA23).**
11. **All Doppler tracking and range data and associated calibration data (MOLA24).**

7.3.6 Radio Science (RS)

7.3.6.1 Reduced data records will be maintained at the cognizant team member's institution in data structures optimized for efficient processing. Periodically, on a schedule consistent with Project requirements, reduced data formatted in a manner consistent with Mars Global Surveyor standards will be transferred to the Project Data Base. A final reduced data set will be provided for permanent storage in a Project-specified archive. Specific data products from the atmospheric investigation include:

(l) vertical profiles of refractive index, number density, temperature, and pressure over the lowest few scale heights of the polar atmospheres; profiles will be obtained on a daily basis at the natural vertical resolution of about 200 m;

(2) fine-resolution versions of the profiles in item (1)

(3) a time history of total atmospheric pressure at a suitably chosen reference altitude;

(4) a time history of vertical atmospheric structure during the life cycle of atmospheric dust storms;

a time history of the peak plasma density and the height of the peak in the dayside ionosphere;

vertical profiles characterizing the small-scale temperature structure and dynamics of the neutral atmosphere, and small scale irregularities in the ionosphere,

a characterization of day-to-day meteorological. variability, such as that caused by baroclinic waves;

a tabulation of planet radius as a function of areocentric latitude and longitude for the occultation points;

a tabulation of the times of immersion and emersion for all observed Earth occultations of the MGS spacecraft.

Specific data products from the gravitational investigation include:

(1) high-resolution line-of-sight gravity maps (i.e., contour maps of near vertical gravity superimposed on Mars topography);

(2) a global high-resolution model of the gravitational field in the form of spherical harmonic coefficients of Legendre polynomials through degree and order 30 to 50; the covariance matrix associated with these parameters;

(3) a characterization of the time variation in the low-degree spherical harmonic coefficients due to the atmospheric seasonal cycle;

(4) the power spectrum of the gravitational field;

(5) maps of geoid height, gravity anomalies, and associated errors;

(6) a Bouguer gravity map, an Isostatic Anomaly map, and the admittance function, as obtained in conjunction with topographic data from altimetry;

(7) the mass of Phobos;

(8) tests and estimation results for local feature modeling;

(9) estimates of the average density of the Martian atmosphere and its time variation at 360 to 400 km altitude from drag measurements.

7.3.7 Thermal Emission Spectrometer (TES)

7.3.7.1 Data Processing. Data will be accumulated and archived routinely during standard mission operations as agreed to by the MGS Project Office. All products generated will conform to the standards being developed for the Planetary Data System, so that archiving of complete and documented data sets will be a natural result of this investigation, requiring little additional effort. Data will be returned to the Project Database in a form that will permit direct transfer from the Project Database to the mission archive. This transfer will be the normal mode of data archiving. Placement of the reduced data into the Project Database will be on the schedule agreed to by the PSG and the MGS Project.

The standard products returned from the TES investigation to the Archive Database will be identical to the form of the data returned to the Project Database, and will consist of the following:

(1) Calibrated radiance values from each *of* the interferometers, solar reflectance, and bolometric radiance instrument sections, together with the geometry location of acquired data, either as specific values, or with the associated SPICE kernel information necessary to reconstruct these values. These data will be in the form of "image cubes." Calibration shall consist of: (1) removal of the instrument response function; and (2) absolute calibration of the radiance. The spectral editing and averaging accomplished within the instrument will be reconstructed so that easily interpretable spectra are returned to the Database.

(2) Spatially resampled versions of the data described in (1) above. Resampling will conform to the Mars Consortium (or other Project-specified) format.

(3) All instrument calibration data and instrument performance information.

Additional data products will be generated as part of the analysis performed by the TES Science Team. However, because of funding limitations, these products will not be generated for all returned data, nor as part of a regular, systematic data processing function. These data products will be returned to the Project Database on a negotiated level and timescale, consistent with the available resources. Examples of these data products include:

(1) Global maps of derived geophysical properties, including (l) surface composition; (2) soil components; (3) albedo; (4) Thermal inertia; (5) rock abundance; and (6) polar ice cap location. These maps will be updated at appropriate intervals as data are received and processed.

(2) Derived atmospheric quantities including: (l) temperature profiles; (2) atmospheric dust opacity; (3) H_20 and 0_3 abundances; (4) surface pressure variations; and (5) water ice cloud occurrence.

(3) Individual mosaics constructed from a single observing sequence.

The TES investigation will use data produced by other MGS experiments, as agreed to in advance according to the policies adopted for data access and exchange. Products of particular importance will include:

(1) MOC high-resolution images of specific targets planned for joint TES and MOC observation.

(2) Radio science temperature profiles

7.3.8 Interdisciplinary Science (IDS)

7.3.8.1 Arvidson. Washington University will delivery all derived map products (e.g., maps showing the relative abundance of articular weathering products) to the Project Data Base in digital form, including the multicolor Viking images. Further, documentation showing how the map products were derived will also be included. Finally, published papers describing results will also be delivered in standard ASCII files for incorporation into the Project Data Archives.

7.3.8.2 Carr. This will be largely the responsibility of the individual teams, but certain general requirements should be met. The data records from all instruments should be available in a common projection and at scales that are binary multiples of each other. The main products of this investigation will be products that display variations in surface properties in terms of several different components (e.g., chemical composition, spectral reflectivity). Preliminary versions of these products should be produced while the mission is in progress so that they can be used as a guide to subsequent data acquisition. Of prime importance will be the appropriate combination of properties that best displays where bedrock is exposed.

7.3.8.3 Ingersoll.

7.3.8.3.1 Data Processing. To be determined.

7.3.8.3.2 Data Base Inputs. Timely inputs into the database of calibrated (or calibratable) observations, together with the algorithms for reducing the observations to geophysical quantities, is essential. In fairness to the PIs, the database should not immediately become public property or even community property within the MGS science community. Instead, the ways that the data will be used should be defined in advance. No distinction should be made between IDSs and other scientists as regards the scientists' right to dip into the database. Any recognition that any individual gets from analyzing data from an MGS instrument, whether he or she is affiliated with the instrument or not, should be according to an agreement between the relevant parties,-those who did the work. The Data Archive Working Group will have to formulate a written policy.

7.3.8.4 Jakosky. To be determined.

7.3.8.5 Haberle. GCM simulations using reduced record data will be provided for archival purposes. This information will be in the form of history tapes containing key variables on time centers of every hour and one half of simulated time and results from the application of the standard graphical package. The standard graphical package contains plots of zonally and time averaged winds and temperature, and fluxes and their latitudinal derivatives of heat and momentum transported by various wind components.

7.4 PROJECT DATABASE

Mars Global Surveyor data in the Project Data Base should include: raw and reduced science data; ancillary data, needed at some level to interpret the science data, and to the extent feasible, the basic software tools needed to access the data, as well as to perform basic analyses. Also, mission planning data, derived data, correlative data, and technical mission specification data should be included.

7.4.1 Definition of Data Products

7.4.1.1 Engineering Data Records. Engineering Data Records (EDRs) consist of raw data in the form of packets containing time-ordered sequences of science data obtained by a given instrument together with engineering information that allows instrument teams to check operation of its instruments. Content of science and engineering data will be instrument-dependent.

7.4.1.2 SPICE Kernels. SPICE is an acronym used to describe five basic elemental data kernels:

S = Spacecraft Ephemeris

P = Planetary/Satellite ephemerides and associated target body constants

I = Instrument descriptions, including operations codes used in E Kernel and alignment offset angles used in C Kernel

C = Inertial orientation of spacecraft primary coordinate system in right ascension, declination, and twist angles and coordinate system rate changes

E = Event information, including nominal sequences, real-time commanding, unscheduled events, and experimenter's notebook comments

SPICE kernels will be generated in part by the Navigation Team at JPL based on orbital tracking, together with instrument information and sequence data obtained from instrument teams. There will be both predict and actual SPICE files. Actual SPICE kernels will be generated within a couple of weeks after data acquisition and made available to instrument teams. Kernels will be used together with a tool kit of software modules (to be supplied by NAIF) to generate the ancillary data needed to process EDRs. In addition, kernels that predict orbits will be available for planning purposes, with availability phased with the standard 28 Sol planning cycle.

7.4.1.3 Standard Data Products. Standard Data Products (SDPs) are generated from EDR and SPICE data. They are defined to be those data products produced in a systematic way during the course of the Mission by Instrument Teams, the Radio Science Team, and by IDSs. Some SDPs may also be produced by groups of Mars Global Surveyor scientists addressing specific scientific problems. The SDPs will be delivered to the Project at predefined intervals that will typically be phased with the 56 Sol mapping cycle (see Table 7-3).

7.4.1.4 Special Data Products. Special Data Products (SPDPs) are defined to be those science data products produced during the course of science analyses. Unlike the Standard Products, these products cannot be predefined since the specific products to be generated will be dependent on the specific scientific content of Mars Global Surveyor observations. The typical SPDP will be generated from SDPs, although some will be generated directly from EDRs using special procedures. An example is a compositional map generated from TES data. In some cases the SPDPs will be of general use to the Mars Global Surveyor community and will be delivered to the Project.

Table 7-3. Mars Global Surveyor Standard Data Products

Acronym	Volume/Cycle Product	Volume (56 Sols)	(Mars Year)
MAG-TSD	Mag Time Series Data	TBD	TBD
MAG-OM	Mag Orbital Map	TBD	TBD
MOC-NA MOC-WA	Mars Orbiter Narrow Angle and Wide Angle Observation EDRs, and SDPs, compressed form	2.4 Gbytes	31.4 Gbytes
MOLA-EPDR	MOLA Experiment Processed Data Record	102 Gbytes	16 Gbytes
MOLA-CEPDR	MOLA Corrected Experiment Processed Data Record	102 Gbytes	16 Gbytes
MOLA-EGDR	MOLA Experiment Gridded Data Record	246 Mbytes	1.0 Gbytes
MOLA-CD	MOLA Calibration Data	77 kbytes	1 Mbyte
RS-TP-STD	Radio Science Atmospheric Temperature-Pressure Profiles (standard). From Radio Occultation (RO) measurements	25 Mbytes	300 Mbytes
RS-TP-HIRES	Radio Science Atmospheric Temperature-Pressure Profiles (high resolution) (RO)	250 Mbytes	6 Gbytes
RS-ROCC	Radio Science Radial Distance of Occultation Point (RO)	25 kbytes	300 kbytes
RS-CONT	Radio Science Atmospheric Total Columnar Content (RO)	25 kbytes	300 kbytes
RS-IPS	Radio Intensity Power Spectra (RO)	3 Mbytes	38 kbytes
RSS-SSP-DS	Radio Science Satellite State Parameters. From Radio Tracking (RT)	TBD	TBD
RS-LOVAR-DS	Radio Science Estimates of Time Variation in Low-degree Harmonic of Gravitation Field (RT)	N/A	1 Kbyte
RS-SHM-DS	Radio Science Gravity Model-Harmonic Coefficients and Mass Concentration	N/A	100 Kbytes

Acronym	Volume/Cycle Product	Volume (56 Sols)	(Mars Year)
RS-SHM-GB	Radio Science Gravity Model- Spherical Harmonic Coefficients, Power Co-Variance Matrix, and Errors (RT)	N/A	1 Mbyte
RS-SS-DS	Radio Science Estimates of Broad Scale Density Structure and Stress State of Martian Crust and Upper Mantle (RT)	N/A	1 Mbyte
RS--IAM-GB	Radio Science Isostatic Anomaly Map	N/A	3 Mbytes
RS-SS-GB	Radio Science Stress Tensor at Mars Surface (RO + RT)	N/A	3 Mbytes
RS-GH-GB	Radio Science Geoid Height Map (RT)	N/A	3 Mbytes
RS-GM-WS	Radio Science Geoid Map (RT)	N/A	600 kbytes
RS-BG-WS	Radio Science Bouger Gravity Map (RT + MOLA data)	N/A	1.5 Mbytes
RS-LAP-WS	Radio Science Line-of-site Acceleration Profiles (RT)	65 Mbytes	825 Mbytes
RS-LAM-WS	Radio Science Line-of-Site Acceleration Map (RT)	N/A	1.5 Mbytes
RS-SHM-S	Radio Science Gravity Field- Spherical Harmonic Coefficients and Statistics and/or Gravity Anomalies with Statistics (RT)	N/A	400 kbytes
TES-CR	TES Calibrated Radiances	6 Gbytes	78 Gbyte
TES-ADF	TES Atmospheric Data Files	0.5 Gbytes	6.5 Gbytes
TES-SRCR	TES Spatially Resampled Calibrated Radiances	6 Gbytes	78 Gbyte
TES-GDSPM	TES Global, Derived Surface Property Maps	N/A	64 Mbytes
TOTAL CYCLE:		>30 Gbytes	---
MISSION TOTAL:			>350 Gbytes

NOTE- Assumed Mission will be thirteen 56 Sol mapping cycles. Also, volume estimates are approximate, representing a first-cut at definition of data products.

7.4.1.5 Press Information Office Products. Press Information Office Products (PIOPs) will consist of selected SDPs and SPDPs that have been annotated with explanations and delivered to the PIO office for use in public relations. PIOPs will exist in both digital and hard-copy forms.

7.4.1.6 Deleted.

7.4.2 Overview of Data System

The data system shall support mission operations, production of Standard and Special Data Products, and science analysis, using a geographically distributed approach (IDS24). The Project shall have a ventral Project Data Base (PDB) located at JPL (see IDS 8-11). Team Leaders (TLs), Principal Investigators (PIs), and Interdisciplinary Scientists (IDSs) shall be able to access the PDB at their home institutions by use of a Project-supplied Science Operations and planning Computer (SOPC) (see IDS16). Each SOPC will be connected to the PDB electronically using a 56 Kbaud link. Team Members (TMs) and Co-Investigators (Co-Is) will get data for their instrument from their TL or PI.

Each Instrument Team (IT) is responsible for- (a) planning the sequence of observations for its instrument using a 28 Sol planning cycle to modify a skeletal sequence of observations. The modified sequence will be compiled on the relevant SOPC and delivered electronically to the PDB; (b) acquiring EDR and SPICE files from the PDB; (c) generating quick-look science data and/or examining house-keeping data to monitor instrument performance; (d) production of SDPs; and (e) delivery of the SDPs to the PDB; (f) production of SPDPs; and (g) generation of scientific reports that summarize results. It is assumed that the rate of SDP generation will keep pace with the rate of receipt of data, i.e., backlogs of unprocessed EDRs will not occur and the production of SDPs will be governed by the amount of time needed to accumulate enough EDR data to produce the relevant products.

Mission operations personnel at JPL shall take the modified skeletal sequences for each 28-sol planning cycle for each instrument and integrate them into an uplink package (IDS25). Several iterations may be required to remove conflicts and to generate an acceptable uplink package.

IDSs will chair a set of Investigator Groups (IGs) composed of other IDSs and relevant TLs, PIs, TMs, Co-Is, and Participating Scientists (PSs). The IGs may consist of a Geoscience Group, an Atmospheres Group, and a Polar Processes Group. There may also be other IGs during the course of the Missions chaired by other Mars Global Surveyor scientists. The IGs will develop plans for coordinated acquisition of data and will guide cross-instrument data analyses. A number of SPDPs will be produced during the course of the coordinated data analysis efforts. IDSs and other members of Investigator Groups will need access to the appropriate SDPs to pursue the analysis efforts. In addition, some IDSs may work directly with specific Instrument Teams to generate SDPs and SPDPs. Each IG will access a large fraction (approximately 50%) of the SDPs produced during the course of the Mission. Thus, each IG will access approximately 232 Gbytes of SDPs. Special Data Products to be produced during all Investigator Groups analyses will be equivalent to approximately 25% of the total SDP volume. SPDPs produced by Investigator Groups to be returned to the PDB will be about 13% of the total SPD volume. Thus, IGs will deliver approximately 60 Mbytes of SPDPs to the PDB.

7.4.3 Data System Functional Requirements and Recommendations

The purpose of this section is to delineate top-level functional requirements of the Mars Global Surveyor data system that are needed to meet both qualitative and quantitative aspects of the activity and data flow scenarios discussed in the previous sections. Recommendations are also given for implementation of the system. Recommendations are in order because parts of the Mars Global Surveyor data system have already been designed.

7.4.3.1 Mission Operations and Standard Data Product Generation.

7.4.3.1.1 Requirement. **The Project Data Base shall maintain digital versions of EDRs, SPICE files, and Standard Data Products, to be acquired and/or produced during the full Mars year of observations (IDS26). As noted in the previous sections and tables, EDR and SPICE data will occupy approximately 84 Gbytes; SDPs to be deposited into the PDB will occupy approximately 464 Gbytes.**

7.4.3.1.2 Requirement. The rate of delivery of SDPs to the PDB shall depend only on the amount of time required to accumulate sufficient data to generate the products. Backlogs of unprocessed data shall not accumulate as a consequence of computational limitations. Normally, delivery will be phased on the basis of the 56 Sol mapping cycle, except when longer period observations are required to be able to generate the product.

7.4.3.1.3 Requirement. **Standard Data Products within the PDB shall be in Planetary Data System-compatible formats, with PDS labels. Each product shall have an SFDU header (IDS27). Table six summarizes the PDS-compatible data types**.

7.4.3.1.4 Requirement. Deviations from PDS standards shall be negotiated between MGS and PDS. SDPs shall have information on why the data were acquired (including if the data were part of a coordinated sequence), when and where the data were acquired how and where the data were processed, and who processed the data.

7.4.3.1.5 Requirement. **EDR and Spice data for a given instrument, once in the PDB, shall be delivered to the relevant TL or PI within 24 hours of request by the TL or PI for the data (IDS28)**. The SOPC shall be used to remotely search the PDB that contain EDR/SPICE information. Orders for data shall be placed via SOPC. (Recommendations: Use 56 Kbaud link when feasible for both query and data transfer. For high data rate instruments Project should consider use of cost effective digital hard copy medium (e.g., CCTs or Digital Audio Tape) and distribute via overnight courier).

7.4.3.1.6 Requirement. Standard Data Products shall be delivered to the PDB in Planetary Data System compatible format, using PDS labels, and SFDU headers. Documentation (Requirement 7.4.3.1.4) shall also be delivered. (Recommendation: same as recommendation under 7.4.3.1.5.)

7.4.3.1.7 Requirement. IDSs shall be involved in strategic planning of coordinated data acquisition sequences. IDSs shall deposit in the PDB plans for acquiring the sequences, including when and where the sequences are to be acquired, and what observations are to be acquired. These plans shall be available in the PDB as elements or via pointers to text files. Information about actual sequences shall also be available in this format. (Recommendation: Let IDSs use SOPCs to coordinate these data acquisition sequences by depositing a description of the sequence in PDB. Let PIs, TLs build on the plan. IDSs would monitor development of sequences using their SOPCs. Deposit the information in the predict E kernel. Append the predict E kernel with a summary of actual coordinated observations after data acquisition.)

7.4.3.1.8 Requirement: **The Project Science Group, its designated subgroups, and Project Personnel shall be on an electronic network to facilitate mission operations and production of Standard Data Products (see IDS12)**. See Requirement 7.4.3.2.4 for traceability of network requirement to Project document. (Recommendation: The Project should consider use of a telenet-like or SPAN system (preferably at least 9600 Baud), which would meet this requirement.)

7.4.3.2 Data Analysis.

7.4.3.2.1 Requirement. Coordinated data analysis activities shall take place during the course of the Mars Global Surveyor Mission. They shall involve five Investigator Groups composed of IDSs, TLs, PIs, TMs, Co-Is, and PSs. These correlative analyses shall involve data from more than one instrument. The tasks shall require access by Investigator Group members to information documenting SDPs. Information concerning coordinated sequence observations shall also be available. (Recommendation: Let access be through SOPCs, Internet, and through dial-up lines.)

7.4.3.2.2 Requirement. The Investigator Groups conducting coordinated data analyses shall access from the PDB the SDPs needed to complete the assigned data analyses tasks. **Each IG shall access some fraction of the SDPs. The leader of each IF** (typically an IDS) **shall access approximately 100 Gbytes (IDS29)**; other members of given IG shall access approximately 50, 25, 1O, 10, 5 Gbytes (i.e., use as approximate access profile). (Recommendation: Let Mars Global Surveyor community use SOPCs, SPAN dial-up lines, or written communication to order SDPs, SPDPs from PDB. Small volumes could be delivered electronically if possible. Large volumes could be delivered using an appropriate, cost-effective hard-copy medium. The Project should consider cost and time tradeoffs associated with use of CCTs, DATs, and CD-ROMs.)

7.4.3.2.3 Requirement. Instrument Teams and Investigator Groups shall generate a total volume of SPDPs equal to about 50% of the total SDP collection. Approximately 50% of the Special Data Products produced by Instrument Teams and Investigator Groups shall be returned to the PDB. PDS labels and formats shall be used with SFDU headers. The total volume for the full Mars year of observations shall thus be approximately 116 Gbytes. The SPDPs shall be returned in PDS-compatible formats, with PDS labels and SFDU headers. SPDPs shall be returned to the PDB by TLs, PIs, IDSs, along with documentation. SPDP product information shall be available in the PDB, including documentation of processing history (how data were processed; what data were involved; who compiled the product; when the product was generated.)

7.4.3.2.4 Requirement. **Approximately 50% (58 Gbytes) of the SPDPs deposited within the PDB shall be accessed by TLs, PIs, and IDSs. (IDS30)**. Information concerning SPDPs shall also be accessible. (Recommendations: Same as those under 7.4.3.l and 7.4.3.2.)

7.4.3.2.5 Requirement. Data analyses may require an electronic network connecting IDSs, TLs, PIs, TMs, Co-Is, and Project Personnel in order to maintain contact on a periodic basis. including transfer of electronic mail, manuscripts, and some data (see IDS11). The Planetary Data System should be accessible by the network to provide data from previous missions for comparison to MGS data.

7.4.3.3 Planetary Data System Interface.

7.4.3.3.1 Requirement. **Spacecraft engineering telemetry, instrument EDRs, and SPICE information shall be transferred from the PDB to the Planetary Data Systems six months after the receipt of the EDRs and associated SPICE files by**

the MOS, unless observations must extend over a longer time period to be able to generate the relevant data products (IDS31). Data shall be delivered in installments, with the delivery dates to be negotiated between MGS and PDS. (Recommendation. Phase deliveries, where appropriate, based on mapping cycle of 56 Sols. Use appropriate combination of electronic and digital hard copy mechanisms of transfer.)

7.4.3.4 Press Information Office Interface.

7.4.3.4.1 Requirement. Press Information Office products (with documentation) shall be generated from SDPs and SPDPs and delivered to the Project for transfer to PIO. The PIOPs shall be deposited into the PDB, both in digital and hard-copy forms. Information about PIOP heritage shall be included. Further, the PIOPs shall be delivered to the Project in PDS format, with PDS labels, and SFDU headers.

7.4.4 Transfer of Data to Planetary Data System

An objective of the Mars Global Surveyor Mission is to ensure the orderly, timely and complete dissemination of the scientific information developed during the course of the mission to the scientific community. There are no proprietary right periods associated with Mars Global Surveyor data. Rather, data are maintained with restricted access within the Project data system until the appropriate Mars Global Surveyor scientists are sure that the products are valid, i.e., the Standard and Special data products have been properly generated and documented. TLs and PIs are responsible for validating data sets acquired by its instruments. Once validated, copies of data will be transferred to the Planetary Data System (PDS) for access and use by the Planetary Science Community (Table 7-4).

The Mars Global Surveyor data release policy is divided into two phases:

Phase I - Production and Validation Period: During the first **six months after they receive EDRs and SPICE files**, Instrument Teams (and Radio Science Team) are expected to reduce their data, validate results, and to complete and publish their preliminary analyses. Coordinated data analysis efforts involving IDSs will also be underway during this period. **During this period any use and analyses of the data from a particular instrument (and Radio Science experiment) or use of the results of unpublished papers derived from such analysis will require the agreement of the appropriate Principal Investigator or Team Leader (IDS32).**

Phase II - Copies of Data Sets Delivered to Planetary Data System: Six months after receipt of EDRs and SPICE files by Instrument Teams (and Radio Science Team), copies of Standard Products and Special Products will be delivered to PDS for general access and use. The exception will be for data products that require longer observations to meet relevant data quality criteria. Individual Mars Global Surveyor Instrument Teams may make the data available to the general planetary community earlier in time, and they may decide to make a number of versions available on a more timely basis.

Table 7-4. Planetary Data System Types

File Type	Description
Text	ASCII text in STREAM format with each line separated by CR/LF. Lines should be 71 characters or less.
Table	Uniform collection of records containing ASCII values delimited by space, comma, tab, or defined fixed-length field.
Image	Simple 2-D array with label.
Cube	Qube of 3 dimensions.
Qube	General multidimensional array with optional prefix suffix areas in each dimension.

7.4.5 Press Information Office

Mars Global Surveyor will generate a large number of products of general interest to the public. Portions of digital Standard Data Products and Special Data Products will be used to generate Press Information Office Products (PIOP) and delivered by the Project to the PIO in hard-copy format. PIOPs will be generated by Mars Global Surveyor scientists. The products will be annotated (explained) and the heritage associated with the products will be documented. **PIOPs should be approved by the Project Science Group or its designated subgroup before release to the Press Information Office (IDS33).**

Press conferences will be scheduled on a regular basis for major releases of PIOPs; products will also be released between Press Conferences. During the period of initial data acquisition, approximately 100 PIOPs (each l Mbyte) will be generated per month. After approximately two months of mapping operations, the number will drop to approximately 50 per month. During the mapping phase, PIOPs will be generated as new areas are covered, as dynamic events are observed, and as new discoveries are made.

A. MISSION OBJECTIVES

Appendix A contains overall science objectives corresponding to the mission description provided in NASA's Announcement of Opportunity (4/85). This entire section is for information only. All requirements inferred from the statements of objectives and investigation descriptions and characteristics are stated in the appropriate sections elsewhere in the IDSRD.

A.1 GENERAL SCIENCE OBJECTIVES

The scientific objectives of the mission are to:

1. To complete as fully as possible, a selected subset of the original science objectives of Mars Observer as follows:

a) Characterize surface morphology at high spatial resolution to quantify surface characteristics and geological processes

b) Determine the composition, map the distribution, and measure the surface thermophysical properties of surface minerals, rocks, and ices.

c) Determine globally the topography, geodetic figure, and gravitational field.

d) Establish the nature of the magnetic field and map the crustal remnant field.

e) Monitor global weather and thermal structure of the atmosphere.

f) Study surface-atmosphere interaction by monitoring surface features, polar caps, polar thermal balance, atmospheric dust, and clouds over a seasonal cycle.

2. To provide multiple years of on-orbit relay communications capability for Mars landers and atmospheric vehicles from any nation interested in participating in the International Mars Surveyor Program.

3. To support planning for future Mars missions through data acquisitions with special emphasis on those measurements which could impact landing site selection.

A.2 OBSERVATIONAL OBJECTIVES

The scientific objectives of the mission will require observations of Mars from the mapping orbit for a complete martian year (687 Earth days) to observe a complete seasonal cycle. The following characteristics of the mapping orbit are required:

A.2.1 Low-Altitude Orbit

Most instruments in the payload will benefit in improved resolution from operating near the lowest orbit altitude. Planetary protection requirements impose a minimum altitude limit.

A.2.2 Near-Circular Orbit

A near-circular orbit is required to minimize altitude variations in the observations. Altitude variations are measured relative to the mapping spheroid reference surface.

A.2.3 Sun-Synchronous Orbit

A Sun-synchronous orbit is desirable for some instruments to minimize diurnal variations in the measurements and to provide uniform illumination of the surface on each orbit. The orbit node should be located such that the dayside equatorial crossing is at 2 p.m. mean solar time. The 2 p.m. orientation was selected to locate the dayside pass near the warmest time of the day and to provide high Sun angles with minimum shadowing.

A.2.4 Near-Polar Orbit

Maximum coverage of the planet's surface is desired, subject to the other orbit design requirements. A low-altitude, Sun-synchronous orbit will have an inclination of approximately 93 degrees, providing nearly global coverage.

A.2.5 Repeating Groundtrack

A repeating groundtrack will be required for some instruments to permit mapping of the surface and to observe time-varying phenomena. The repeat cycle of the orbit should be no greater than 7 days.

The required parameters for the mapping orbit are discussed in Section 3.2. The baseline characteristics will be selected in consultation with the Project Science Group.

B. MISSION DESIGN

The spacecraft will be launched by the Delta II during the Mars opportunity of November 1996. The 1996 opportunity requires a Type II interplanetary trajectory with a flight time of nearly one year. Arriving at Mars in August 1997, the spacecraft will be inserted into an initial elliptical orbit. Over a period of about four months, the spacecraft will aerobrake down to the mapping orbit, which is nearly circular at low altitude and Sun synchronous at the desired solar orientation of 2 p.m. on the dayside pass. Repetitive observations of the planet's surface and atmosphere will be conducted from the mapping orbit for a complete martian year (687 Earth days). The spacecraft will maintain a nadir orientation in the mapping orbit. There will be no scan platform, and any scanning capability will be provided by the instruments. The mapping orbit will have a repeating ground track that allows global coverage to be built up from repeated instrument swaths. For the reference mission, the mapping orbit semimajor axis minus the Mars equatorial radius is 378 km to provide a repeat cycle of seven martian days (sols). The Sun-synchronous inclination is 92.8 degrees, providing coverage of 99.9% of the planet. The normal sequence of collecting science data will be to record it continuously for about 24 hours, and then play it back through the Deep Space Network in one tracking station pass on each day. Approximately every third day an additional tracking pass will be scheduled to return high-rate, real-time data. For the reference mission, the period of science observations (the mapping phase) extends from December 1997 to November 1999.

To conform with international agreements against the contamination of Mars with terrestrial organisms, the spacecraft will finally be raised into a higher quarantine orbit.

Tables B-1 and B-2, and Figures B-l and B-2 summarize the mission time line and mapping orbit.

Table B-1. Start and End Dates for Mapping Phase

	Earliest Launch Date November 3, 1996	Latest Launch Date November 24, 1996
Mars Orbit Insertion	September 10, 1997	September 21, 1997
Orbit Insertion Duration	146 days	146 days
Begin Mapping Phase	February 2, 1998	February 13, 1998
Mapping Duration*	687 days	687 days
End Mapping Phase	December 21, 1999	January 1, 2000

* Mapping phase duration includes 14-day command moratorium during solar conjunction. Data return will be substantially reduced during this period (see subsection 6.7).

Table B-2. Martian Seasonal and Orbital Events During Mapping Phase

Date	Event
February 6, 1998	Winter Solstice, Start of Southern Summer
April 30, 1998	Sun Beta Angle Maximum (-15.909 deg)
May 4, 1998	Begin Solar Conjunction Command Moratorium (Sun-Earth-Mars Angle ≤ 2 deg)
May 21, 1988	End Solar Conjunction Command Moratorium (Sun-Earth-Mars Angle ≥ 2 deg)
June 22, 1988	Earth-Mars Distance Maximum (2.518 AU)
July 15, 1998	Vernal Equinox, Start of Northern Spring
October 29, 1998	Earth Beta Angle = 0.0 deg (Diametric Occultation)
December 17, 1998	Mars Aphelion (1.666 AU)
January 4, 1999	Earth Beta Angle Maximum (4.891 deg)
January 29, 1999	Summer Solstice, Start of Northern Summer
February 19, 1998	Earth Beta Angle = 0.0 deg (Diametric Occultation)
May 2, 1999	Earth-Mars Distance Minimum (0.578 AU)
August 1, 1999	Autumnal Equinox, Start of Southern Spring
August 1,1999	Sun Beta Angle Minimum (-39.812 deg)
September 22, 1999	Earth Beta Angle Minimum (-77.656 deg)
November 25, 1999	Mars Perihelion (1.382 AU)
December 25, 1999	Winter Solstice, Start of Southern Summer

* Dates and durations depend on orbit geometry, and small variations may occur.
Solar beta angles are always negative; the largest value results in longest eclipse.

Figure B-1. Mars Global Surveyor Mission Time Line

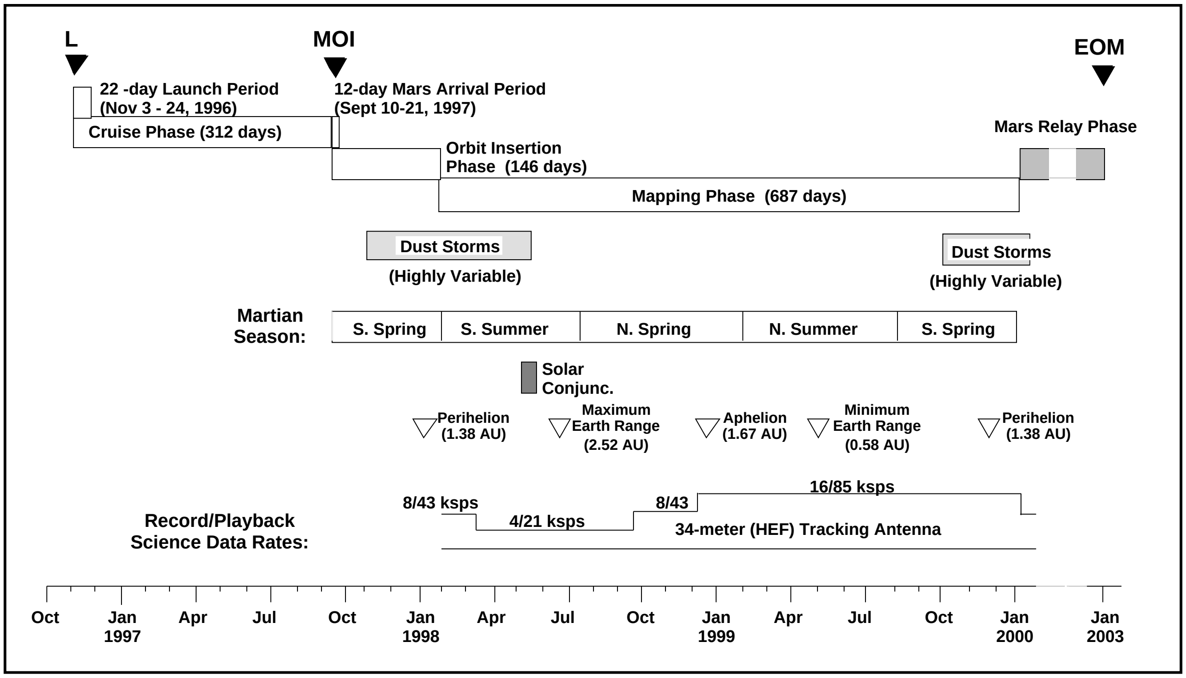
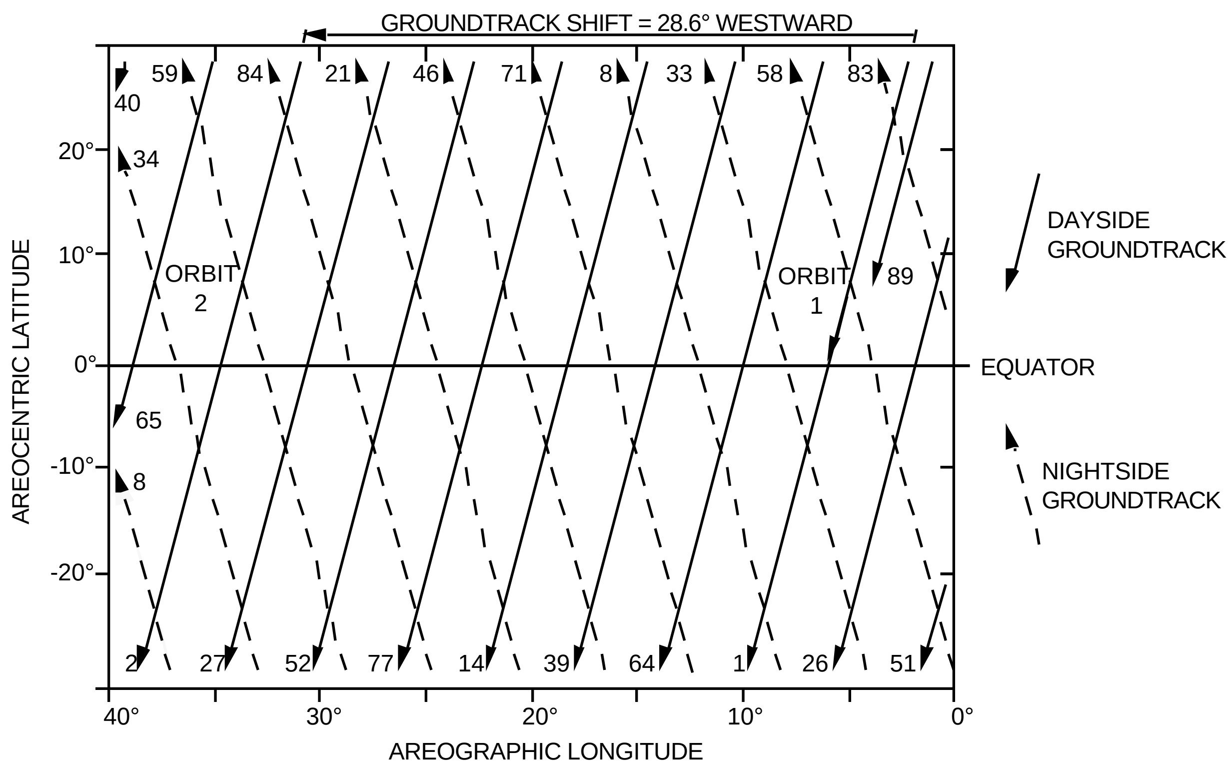


Figure B-2. Mapping Orbit Ground Track



C. SPACECRAFT DESCRIPTION

The Mars Global Surveyor spacecraft provides a three-axis stabilized platform for observations of Mars by the science payload. The spacecraft design is derived in large part from the Mars Observer spacecraft, with necessary modifications made to incorporate the action plans from the Mars Observer failure reports. The design is also strongly driven by the Martin Marietta Magellan aerobraking experience.

Figure C-1 shows views of the spacecraft in its launch and cruise configurations. The spacecraft structure is made of lightweight composite material and is divided into four subassemblies: 1) the equipment module , 2) the propulsion module, 3) the solar array support structure, and 4) the high gain antenna support structure. The equipment module houses the avionics packages. The dimensions of the equipment module are 1.17 x 1.17 x 0.735 meters in the X-Y-Z directions. With the exception of the MAG, the instruments are all body-mounted on the nadir equipment deck which is mounted to the +Z panel of the equipment module. The propulsion module is mounted to the bottom or -Z side of the equipment module. The propulsion module serves as the adapter between the launch vehicle and the equipment module and supports the propulsion subsystem, solar arrays and high gain antenna. The spacecraft has two solar arrays, each 6.0 m^2, mounted on the +Y and -Y panels of the propulsion module, respectively. The two MAG sensors will be mounted on 20 cm solar array boom extensions to the outside panel of each array, respectively. The HGA extends at the end of a 2.0 m boom, which is mounted to the +X panel of the propulsion module.

C.1 CONFIGURATION

At launch, the solar panels and high-gain antenna (HGA) are folded against the rectangular spacecraft equipment module, as shown in Figure C-1. After separation the spacecraft attains an initial DSN acquisition attitude for two hours. After the two hour DSN acquisition hold period, the spacecraft will be configured for the cruise phase as shown in Figure C-2. The two solar arrays, mounted respectively on the +Y and -Y panels of the equipment module, are deployed to a fixed position 30 degrees, respectively, from the ±Y axes towards the +X axis. The HGA boom remains folded in its launch configuration, fixing the HGA to be pointed along the +X axis. The spacecraft will be stabilized in a controlled 0.01-rpm roll about the +X axis, which will be maintained 60 degrees from the sun throughout inner cruise. During the first two months of the cruise phase, the Earth-probe-sun angle decreases almost linearly from 120 to 60 degrees, constraining communications with the Earth to be over the low-gain antennas (LGAs). Once the Earth-probe-Sun angle has decreased to 60 degrees, the HGA line of sight coincides with the Earth line, allowing communications over the HGA for the rest of the cruise phase. For all propulsive maneuvers and for the aerobraking drag passes, the spacecraft will turn under 3-axis control to the maneuver attitude and then upon completion of the maneuver, return to the required mission phase attitude. For large maneuvers, the 596 N main engine will be used for the delta-V, while the 4.4 N ACS thrusters are used to provide attitude control during the burn. The smaller maneuvers will utilize the 4.4 N thrusters to achieve the required delta-V.

After insertion into the mapping orbit, the spacecraft will be configured for mapping operations in the nadir attitude, as was shown in Figure C-3. The solar arrays gimbal drive control will be enabled to track the Sun around each orbit. The HGA boom will be deployed, and its gimbal drive control enabled to track the Earth around each orbit. The spacecraft will be controlled in 3 axes, using the horizon sensors to point the science instruments on the +Z face to the nadir. In the mapping orbit, the +X face points in the direction of orbital motion, and the spacecraft completes one revolution about the Y axis during each orbit of 117.65 minutes. Because the orbit is Sun synchronous at the Mars mean orbital rate, the Sun is always on the +Y side at an angle that varies between 50 and 74 degrees from the +Y axis, due to the variation of the orbital rate of Mars with respect to the Sun.

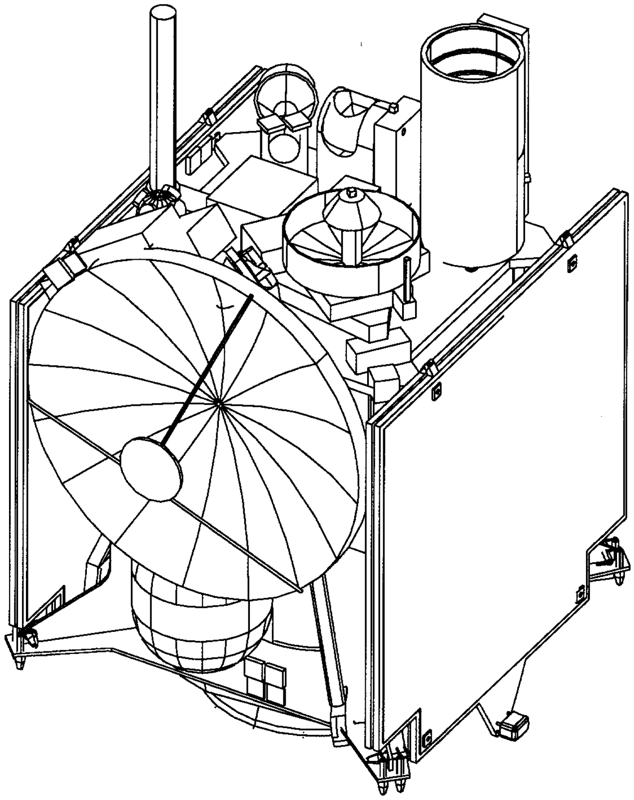


Figure C-1. Spacecraft Launch Configuration

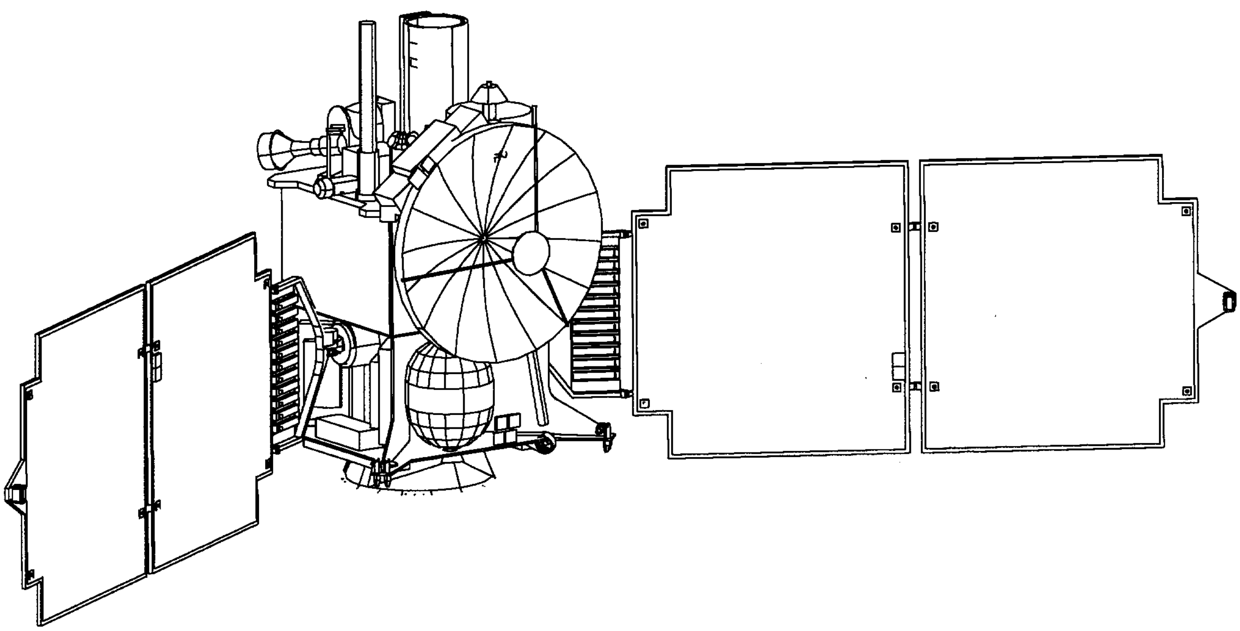


Figure C-2. Spacecraft Cruise Configuration

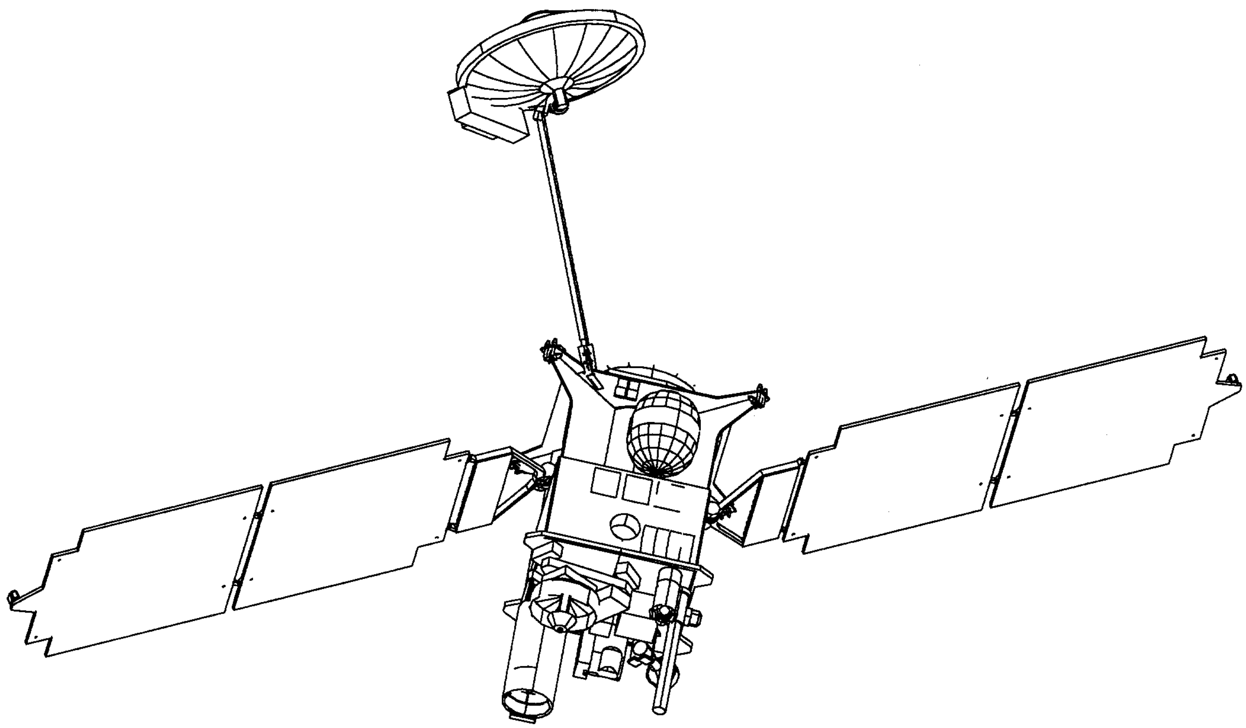


Figure C-3. Spacecraft Mapping Configuration

C.2 COMMAND AND DATA HANDLING

The Command and Data Handling (C&DH) subsystem is built around the two redundant flight computers (standard controls processor or SCP, 128K words RAM and 20K words PROM); the controls interface unit (CIU), which connects the computers to other spacecraft components; the engineering data formatter (EDF), which formats engineering telemetry; the payload data subsystem (PDS), which provides the command and data interface to the science payload; the cross-strap unit (XSU), which routes telemetry to the recorders and/or to the telecom subsystem; and the Solid State Recorders (SSRs), which will record science and/or engineering telemetry.

Most of the spacecraft activities are orchestrated by the SCP flight software. While one SCP is in active control of the spacecraft, the identical software is running in the backup unit. The SCP flight software functions include attitude and articulation control, command processing, some telemetry functions, power management and battery charge control, thermal monitoring and heater control, and fault protection. The fault protection functions include redundancy management and three anomaly modes: safe mode, emergency mode, and contingency mode, which are described in the flight software documentation in Appendix B (TBD). The safe mode software is located in the SCP PROM and provides a final fallback mode of reduced operations in the event of major subsystem problems or loss/corruption of the RAM code.

The C&DH must handle three data streams of science and/or engineering data, as follows:

(1) Science and Engineering 1 (S&E-1) - a combined science and engineering data stream that can be recorded for later playback (primary) and/or returned in real-time (backup and monitoring).

(2) Science and Engineering 2 (S&E-2) - a combined science and engineering data stream for returning high-rate science in real-time only.

(3) Engineering (ENG) - an engineering-only data stream that can be recorded for later playback and/or returned in real-time.

Data rates for the three data streams are defined in Table C-1. The S&E-1 and S&E-2 streams are Reed-Solomon encoded (symbol-to-data ratio 250:218). Data allocations in the S&E-1 and S&E-2 streams are described in Appendix A.

Table C-1 Science and Engineering Data Rates

Data Stream	Record Rate	Playback Rate	Real-time Rate
S&E-1	4000 sps	21333.3 sps	4000 sps
	8000 sps	42666.7 sps	8000 sps
	16000 sps	85333.3 sps	16000 sps
S&E-2	-	-	40000 sps
ENG	2000 bps	8000 bps	2000 bps
	-	-	250 bps
	-	-	10 bps

There are two dual redundant solid state recorders (SSR). Each SSR has two 0.75 Gb recorders that support simultaneous record/playback. Thus each SSR can store up to 104 hours of data at the 4 ksps record rate and over 26 hours at the 16 ksps record rate.

C.3 ATTITUDE CONTROL

The Attitude and Articulation Control Subsystem (AACS) provides attitude determination and control, and controls pointing of the HGA and solar array. The AACS software resides in the SCPs. Spacecraft pointing control, except during maneuvers, is provided normally by three orthogonally mounted reaction wheels (RWAs). A fourth RWA is available for redundancy and is mounted skewed to the three orthogonal RWAs. Several sensors provide attitude information. In the mapping orbit, the Mars Horizon Sensor Assembly (MHSA) defines the nadir direction by sensing roll and pitch errors from the atmospheric horizon. Inertial attitude sensing is provided by the Celestial Sensor Assembly (CSA), a fixed star mapper that is scanned by the spacecraft rotational motion. The CSA data is used for attitude control and knowledge during the cruise and orbit insertion phases and for precise attitude knowledge during the mapping phase. Both the MHSA and CSA are mounted on the +Z axis equipment deck. An Inertial Measurement Unit (IMU) provides gyros and accelerometers for measuring angular rates and linear accelerations. The IMU measurements are used to determine yaw attitude in the mapping phase and for inertial pointing, both fixed and for attitude slews, such as during maneuvers. Multiple Sun sensors provide the Sun reference for attitude acquisition after separation from the upper stage and for attitude re-initialization in the event of an anomaly.

C.4 TELECOMMUNICATIONS

All spacecraft communications are at X-band using the Mars Observer Transponders (MOT), the GFP Command Detector Units (CDU), the 25-Watt RF power amplifiers (RPA), the HGA and four LGAs (two for receive and two for transmit). The LGAs are used early in cruise and for emergency communications in anomaly modes. The primary LGA is mounted on the HGA antenna, while the backup transmitter is mounted on the +X side of the propulsion module. The two receive LGAs are mounted on the -X panel of the equipment module and the +X side of the propulsion module. The 1.5-meter HGA provides high-rate communications during the outer cruise, orbit insertion, and mapping phases. In the mapping configuration, the HGA is deployed on a 2.0-meter boom to provide clearance over the solar arrays to point to the Earth. The spacecraft can receive uplink commands at data rates in multiples of two between 7.8125 bps (emergency) and 500 bps. The 125 bps commanding rate will normally be used.

C.5 PROPULSION

The propulsion system is a dual mode bipropellant system, using nitrogen tetroxide (NTO) and hydrazine. The dual mode differs from a conventional bipropellant system in that the hydrazine is used by both the main engine and the attitude control thrusters, rather than having a separate hydrazine tank for each. The main engine is the only one that utilizes the bipropellant system. The main engine delivers a nominal I_{sp} of 318 seconds (minimum 317 seconds) and 596 N thrust. The main engine will be used for the larger maneuvers, including TCM-1, TCM-2, MOI and TMO. Four rocket engine modules (REM), each containing three 4.45 N thrusters, are provided. Each REM contains two aft facing thrusters and one roll control thruster. Four of the eight aft facing thrusters will be used for the smaller TCMs and OTMs in a pulse-off mode, as well as providing attitude control during the main engine burns in a pulse-on mode. Two sets of four thrusters are on redundant strings in the event of a failure (e.g. stuck open/close engine valve or a failed closed latch valve) which requires one string to be isolated. Four thrusters are provided for roll control. In addition to maneuvers, the 4.45 N thrusters are also used for momentum management.

C.6 POWER

Two solar arrays, each 6.0 m^2 provide the power for the spacecraft. Each solar array has two panels, the inner panel comprised of gallium arsenide (GaAs) cells, and the outer panel comprised of Silicon (Si) cells. When the spacecraft is in eclipse or turned away from the Sun, energy is taken from two nickel-hydrogen (NiH2) batteries, each with a capacity of 20 Amp-hours. During launch the two solar arrays are fully deployed , and the available power varies from about 1100 Watts after launch to a minimum of about 660 Watts. The array output varies with the solar range and the angle to the Sun, since the spin axis is pointed to Earth. After insertion into the mapping orbit, autonomous gimbal drive control is enabled and each array will track the Sun around each orbit under AACS software control. On each orbit the spacecraft will be in eclipse from 36 to 41 minutes, and power will be supplied from the batteries.

To achieve the required lifetime, the battery depth of discharge in the mapping orbit cannot normally exceed 27%. This limits the amount of time the spacecraft can transmit during eclipse. The spacecraft is required to support up to ten minutes of transmission in eclipse for the radio science occultation experiment.

D. INVESTIGATION DESCRIPTIONS

The scientific objectives of the Mars Global Surveyor (MGS) mission will be achieved with a complement of seven investigations that have been selected by NASA's Office of Space Sciences. The investigations and principal investigators (PIs) are listed in Table 1-1. A summary of the instruments' physical properties is given in Table D-l. Figure D-l shows the viewing areas of the nadir-viewing science instruments. The following investigation summaries are provided for information purposes. The instrument fields of view, projected FOV footprints on Mars, and thermal (FOV) characteristics are given in Tables D-2, D-3, and D-4. This information may be superseded by the detailed specifications contained within an instrument's ICD.

D.1 Deleted

Table D-1. Mars Global Surveyor Payload Summary

Investigation	Mass [kg]	Power [W]	Real-Time [b/s]	Record Rate [b/s]
MAG/ER	5.217	4.63		324, 648, 1296
MOC	20.96	22.75	29,260	700, 1388, 2856, 4520, 9120, 10782
MOLA	25.89	30.94		618
RS/USO	1.3	3.00		
TES	14.56	15.55	4992	688, 1664
MR	7.9	see MOC		

Table D-2. Science Instrument Viewing Requirements

Instrument	Viewing Direction	Field of View	Stray Radiation
MAG/ER	N/A	4π str, 360°x14°	360°x20°
MOC	+Z	0.41°, 140°	10°
MOLA	+Z	0.5 mrad	±5°
TES	+Z to ±80° (±X)	1°x1.5°	±10.75°
MR	+Z	±65°	N/A

Table D-3. Temperature Characteristics of MGS Science Instruments

Instrument	Assembly	Operating Range	Non-Operating Range
MAG	Sensor	-20°C to +45°C	-40°C to +75°C
	ER	-10°C to +50°C	-35°C to +75°C
	Electronics	-10°C to +40°C	-40°C to +75°C
MOC	NA Focal Plane	-28°C to -2°C	-30°C to +40°C
	WA Focal Plane	-62°C to -24°C	-30°C to +40°C
	Optics	-50°C to +30°C	-60°C to +40°C
	Electronics	-20°C to +30°C	-30°C to +40°C
MOLA	Electronics	-20°C to +30°C	-30°C to +40°C
USO		-20°C to +30°C	-30°C to +40°C
TES		-20°C to +40°C	-20°C to +50°C

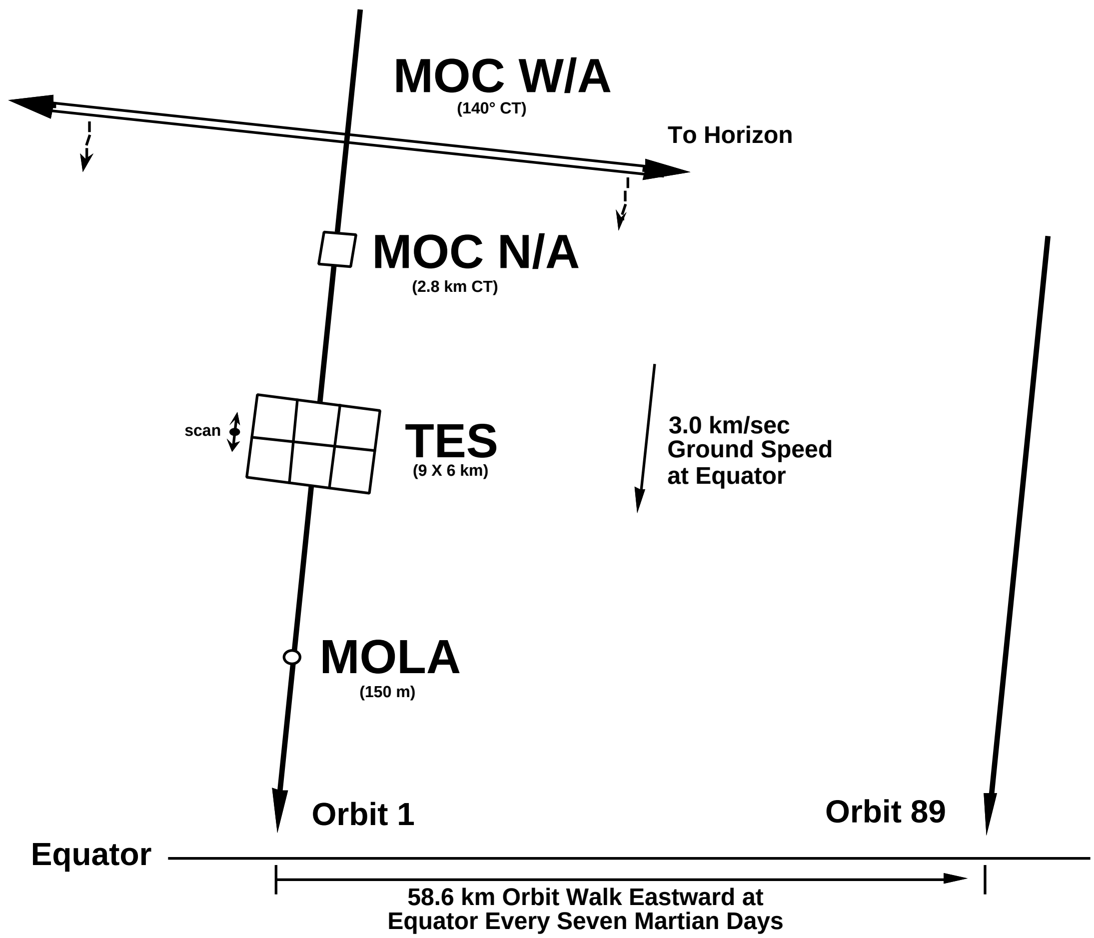


Figure D-1. Nadir-Viewing Science Instrument Characteristics

D.2 Magnetometer and Electron Reflectometer (MAG/ER)

D.2.1 Investigation Description. The Mars Global Surveyor Magnetic Field Experiment consists of a magnetometer and electron reflectometer (ER) that make both local and remote sensing measurements of the martian magnetic field. The magnetometer will provide rapid (up to 16 vectors/s), precise (±0.025%), accurate (±0.08 nT), ultra sensitive (±0.004 nT), wide-dynamic-range vector measurements of the martian magnetic field at the spacecraft altitude. The ER will obtain ~1° resolution measurements of the electron pitch angle distribution, and determine the Martian magnetic field strength down to the atmospheric loss cone altitude for ~20-keV electrons (~120 km). The combined measurement will determine surface fields with ~30 times the sensitivity and ~3 times the spatial resolution of a magnetometer alone. In addition the ER will determine the altitude dependence of the field from ~120 to 200 km. The goals of the experiment are to:

(1) establish the nature of the magnetic field of Mars.

(2) develop appropriate models for its representation, which take into account the internal sources of magnetism and the effects of the interaction with the solar wind.

(3) map the martian crustal remnant field to a spatial resolution of approximately 120 km.

The magnetometer is a dual, triaxial, fluxgate magnetometer system with sensors mounted on the spacecraft. This system allows the real-time estimation and correction of spacecraft-generated fields. The instruments proposed have an extensive spaceflight heritage and are similar to the low-field systems flown on Voyagers 1 and 2, selected for the NASA-ISPM spacecraft, and flown on the Giotto mission. Depending on the telemetry rate supported, 2 to 16 vector samples per second will be acquired. The instrument is microprocessor controlled, can be partially reprogrammed in flight, and supports the packet telemetry protocol planned for the Mars Global Surveyor mission.

The electron reflector instrument consists of a hemispherical electrostatic analyzer with a 360° x 14° field of view, microchannel plate detectors, position imaging electronics, and high-voltage power supplies. The instrument can measure the electron loss cone (or photoelectron source cone) angle over a wide range of electron energies and, when combined with the local magnetic field, allows determination of the magnetic field strength at loss cone (source cone) altitudes. A low-energy mode will also measure ionospheric thermal electrons to locate the martian ionopause. The basic instrument has an extensive spaceflight heritage, including Giotto, AMPTE, and numerous sounding rockets, and has been selected for ISTP/GCS-WIND spacecraft. The instrument will measure a two-dimensional slice of the electron velocity distribution with l-second resolution. At the lowest data rates the instrument will assemble a reduced set of measurements that include: three parameter fits that characterize the atmospheric loss cone angle at three energies (2-s resolution), the two-dimensional distribution function (24-s resolution), and the detailed energy spectra (48-s resolution).

D.2.2 Science Objectives. The broad objective of the Mars Global Surveyor magnetic field investigation is to establish the nature of the magnetic field of Mars. An important objective in characterizing the magnetic field is to determine if Mars has a global magnetic field of internal origin. Previous spacecraft missions have established that the planetary magnetic field, if it exists, is small. A global magnetic field of internal origin would evidence dynamo action in the interior, either at present or in the past. Dynamo field generation requires an electrically conducting, fluid volume in nonuniform rotation; this information alone provides powerful constraints on the composition, thermal state, and dynamics of the interior of the planet. As such, magnetometry is one of very few observational techniques (gravimetry is another) capable of probing the deep interior and its dynamical evolution.

If Mars does not have a presently active magnetic dynamo, it is very likely to have had one in the past when convective fluid motion in the interior was vigorous. Mars is expected to have undergone significant thermal evolution, some of which is evident in the geologic formations and units mapped by the Mariner 9 and Viking missions to Mars.

Thus, different regions of the martian crust are very likely magnetized with varying strengths and orientations representative of prior epochs of magnetic activity. An important objective of the Mars Global Surveyor magnetometer experiment is to identify and characterize the crustal remnant magnetization, fully utilizing the orbiter's circular polar mapping orbit to produce an accurate crustal anomaly map similar to those produced using data from the Magsat satellite in Earth orbit. Along with geologic data on the age and spatial distribution of major geologic units, the crustal magnetization maps may provide a history of martian magnetism and crustal evolution.

An understanding of the nature of the solar wind interaction with Mars is necessary to fully address the two major scientific objectives outlined above. From the very limited magnetic field observations obtained by previous missions, it is clear that the (global) internal field is small in magnitude, and it is likely that the crustal remnant field is also small in magnitude at the proposed Mars Global Surveyor altitude. This means that the solar wind magnetic field, distorted by the solar wind interaction with Mars, may dominate the magnetometer measurements. The electron reflectometer (ER) can overcome part of this problem by remotely measuring the martian fields down to much lower altitudes (~120 km) and thus providing ~30 times the sensitivity of a magnetometer alone. By utilizing electrons over a wide range of energies, the height dependence of the anomaly fields can be determined. In addition, the ER obtains the field strength at those altitudes in a single measurement (~1 s), and no filtering or averaging is needed. Thus this technique is applicable even when the ambient field is turbulent, as is typically observed in solar wind - planetary interaction regions.

The accurate determination of the martian magnetic field also requires an understanding of the magnetic fields associated with the solar wind interaction. A proper understanding of the field due to the Mars-solar wind interaction with either a global magnetic field or ionosphere will thus contribute to our objectives. The ER is capable of measuring both the thermal ionospheric and energetic solar wind electron populations and thus can determine boundaries between the solar wind and the ionosphere. An understanding of the nature and location of these boundaries is necessary in modeling the Mars-solar wind interaction. In addition, the electron measurements provide a means of tracing the magnetic field topology and thus a means of testing the accuracy of models of the interaction.

D.2.3 Instrumentation. The basic instrumentation for the Mars Global Surveyor spacecraft consists of the magnetometer sensors, the electron reflectometer, and the MAG electronics. Table D-4 summarizes the principal characteristics of the instruments.

D.2.3.1 Magnetometers. The magnetometers are based on those developed for the Voyager, ISPM, and Giotto missions, which represent state-of-the-art instruments with unparalleled performance. The basic configuration proposed consists of dual, wide-range (+0.004 to +65536 nT) triaxial fluxgate magnetometers mounted away from the spacecraft body. The sensors are connected by serial lines to the MAG electronics, which includes a basic 12-bit-resolution A/D converter system and microprocessor-controlled range control logic. The magnetometer sensors are mounted at the end of the solar array.

Table D-4. Investigation Summary: Instrument Summary

Magnetic Performance Parameters

Dynamic ranges: ±16 nT; ±64 nT; ±256 nT; ±1024 nT; ±4096 nT; ±16,384 nT; ±65,536 nT.

Quantization steps:

(a) 12-bit resolution: ±0.004 nT; ±0.016 nT; ±0.063 nT; ±0.25 nT; ±l nT; ±4 nT; ±16 nT.
(b) 16-bit resolution: ±0.00025 nT; ±0.001 nT; ±0.004 nT; ±0.016 nT; ±0.063 nT; ±0.25 nT; ±1 nT.

Sensor noise level, rms: 0.008 nT, 0-10 Hz

Electron Reflector Performance Parameters

Energy range:	1 eV to 20 keV
Energy resolution:	$\Delta E/E = 0.25$
Field of view:	360° x 14°
Angular resolution:	1.4° x 14°
Geometric factor:	0.04 E (keV) cm2-sr-keV above 200 eV 4×10^{-4} E cm^2-sr-keV below 200 eV
Sensitivity to remote magnetic fields:	$dB < 3 \times 10^{-3} B$, where B is the field strength at the spacecraft
Altitude range sampled:	~120-200 km above Mars surface

Weight

External-mounted items:	
Magnetometer sensors	125 g
	125 g
Mounting bracket, canister cover (thermal control components not included)	105 g
	105 g
Electron reflectometer (thermal control components and closing mechanism not included)	1700 g
ER aperture-closing mechanism	200 g
Bus-mounted items:	
Analog electronics and A/D converters	560 g
Analog subchassis	200 g
Miscellaneous (connectors, harnesses, etc.)	55 g
Data processor	535 g
Digital subchassis	200 g
Miscellaneous	150 g
Power converters	240 g
Total weight (redundant electronics) (mass of PDS interface not included) (mass of thermal control components not included)	2300 g

Size	
Sensors	10 x 7.5 x 7.5 cm
Electronic Reflectometer	20 x 15 x 13.5 cm
Analog electronics	20 x 5 x 15.8 cm
Data processors and power converters	20 x 5 x 15.8 cm
Power	
MAG power consumption @ 75% power conversion. efficiency, including PDS interface	2.45 W
ER power consumption	1.7 W
Thermal (unregulated)	<1.0 W
Telemetry Rates	
(a) Minimum rate (1.5 kb/s, S&E-l mode),	160 b/s
(b) Maximum rate (1.2 kb/s, S&E-l mode)	640 b/s

The analog signals from the magnetometers are digitized by a successive-approximation A/D converter operating under the Digital Processing Unit's (DPU) microprocessor-control to provide variable time resolution depending on the spacecraft telemetry mode. This analog subsystem also provides the necessary information to the DPU to activate the automatic range control logic. The resulting digital information is processed by the DPU and formatted into dual "ping-pong" packet buffers together with ancillary information such as S/C time, housekeeping data, attitude information, etc. The buffers will be accessed by the Payload Data Subsystem (PDS) via the Bus Interface Unit (BIU) for synchronous collection.

The electron reflectometer (ER) is based on electrostatic analyzers developed for the Giotto and AMPTE missions. The basic configuration is shown in Figure D-2 and consists of a 360° x 14° FOV hemispherical electrostatic analyzer, microchannel plate detector, pulse position analyzer, programmable pitch angle sorter, counter bank, high-voltage power supply, and serial interface to the MAG electronics. The ER is mounted to limit the effects of spacecraft charging and is electrically insulated from the spacecraft body to allow a small biasing voltage (less than 10 V) between it and the spacecraft.

Electrons are selected in energy and imaged in angle by the electrostatic analyzer onto the microchannel plate (MCP) detector. Charge pulses from the MCP are imaged in position around the 360° FOV, sorted by pitch angle into counters, and read out over a serial port by the MAG electronics DPU. The electrostatic analyzer sweeps in energy from O to 20 keV every second. High voltages are programmable and controlled by the DPU. The pitch angle sorter is updated by the DPU at the end of each sweep, using the magnetometer's magnetic field measurement. A primary task of the DPU is to reduce the data to meaningful parameters (loss cone angles, energy spectra, plasma parameters, and averaged distributions) and to format these into dual "ping-pong" packet buffers identical to the magnetometer's buffers. These buffers will be accessed by the PDS via the BIU for synchronous collection.

The MAG electronics consists of two identical sections, each containing a DPU, an A/D converter, a BIU, a low-voltage power supply (LVPS), and interfaces to the magnetometer sensors and ER. Selection of which section of the electronics is active is made by applying power to the appropriate power converter; the redundant section is not powered. The DPU controls and acquires data from the two magnetometers (IBD and OBD) and the ER, compresses and formats the collected data into telemetry packets, interfaces to the Payload Data System (PDS) via the Bus Interface Unit (BIU), to which it sends telemetry packets on demand and from which it receives commands, and acts on commands to control the instrument functions and data collection modes. The DPU incorporates a watchdog timer to allow it to recover from unexpected states. The watchdog timer is normally reset by proper execution of the executive program; in the absence of a reset pulse, the watchdog timer will reset the system and start a self-diagnostic and configuration program.

D.2.3.2 Sensor Systems and Analog Electronics

Zero-level drifts have been historically the major problem in the use of fluxgate magnetometer sensors, but in recent years the problem has been reduced significantly with advances in sensor design, materials, and electronic systems. The proposed fluxgate sensors are constructed utilizing the ring core geometry, which has been shown to exhibit superior performance characteristics in terms of long-term zero-level stability and drive power requirements when compared to other types of fluxgate sensors. In addition, the magnetic material used to manufacture these sensors is the latest in a series of advanced molybdenum-permalloy alloys which have been especially developed for low-noise, high-stability applications in cooperation with the Naval Surface Weapons Center, White Oak Laboratory, MD. It exhibits superior performance characteristics unmatched by any other type of fluxgate sensor material.

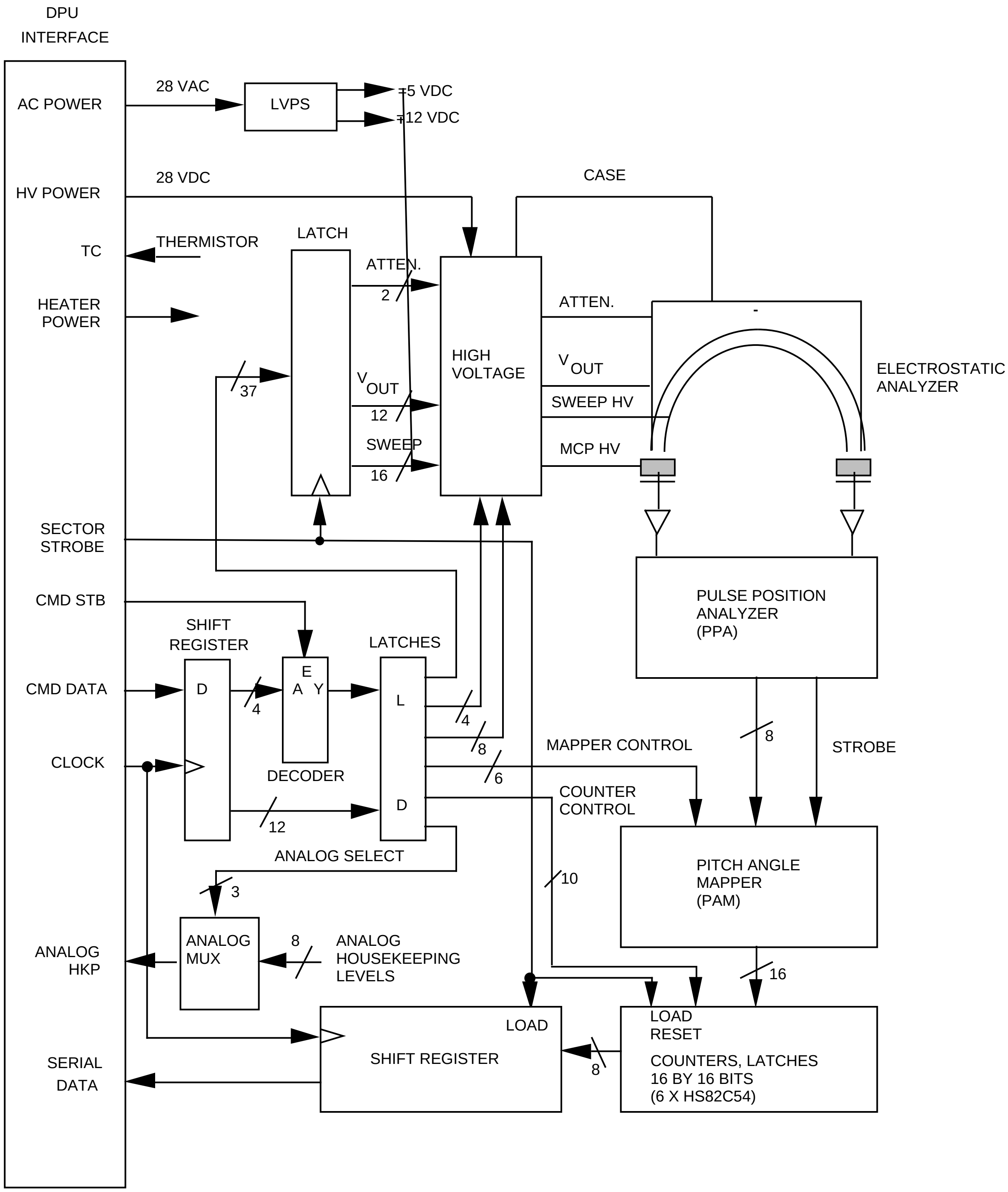


Figure D-2. Electron Reflectometer Block Diagram

The sensor material achieves a factor of 1.5 improvement in noise performance over the Voyager sensors with conventional signal processing and detection electronics, and represents the state of the art in fluxgate magnetometry. The use of this alloy and the ring core geometry allows the realization of compact, ultrastable fluxgate sensors with outstanding noise performance. When used in conjunction with the electronics described below, zero offset stability is better than ~0.16

nT over the temperature range of +60°C and for periods exceeding one year, based on current Voyager data. Typical noise levels are 0.006 nT rms over an 8-Hz bandwidth.

The design of the analog electronics associated with these sensors is an evolution of that developed for previous missions such as Voyager, ISPM, and Giotto. The design has been shown to exhibit optimal noise performance characteristics and one of its fundamental characteristics is that complexity is kept to a minimum to improve reliability and reduce power, weight, and cost. The design makes use of stable, negative-resistance parametric amplification obtainable from tuned fluxgate sensors. This technique eliminates the need for high-gain, low-power, low-noise amplifiers, which can be extremely sensitive to interference and radiation-induced degradation. The sensors are driven to a peak excitation of over 100 times their coercive saturation force by means of a high-efficiency capacitive discharge circuit. This has eliminated the consideration of memory ("perming") effects which have plagued other fluxgate designs.

The proposed system also includes circuitry which allows the determination of zero-level drifts caused by aging of electronic components, radiation effects, temperature and voltage variations, etc. by simulating a 180° mechanical rotation of the sensors.

Intrinsic zero-level changes associated with the sensor cannot be determined by this method, but extensive tests in our laboratory, as well as flight experience with numerous instruments, have shown that the sensors themselves exhibit less than 0.1 nT drift in their zero levels due to changes in magnetic properties with temperature and time. The sensitivity of the proposed magnetometers will be checked periodically by passing accurately known currents through the feedback coils to generate precisely calibrated fields.

To meet the major scientific objectives of the investigation, the instruments incorporate a wide dynamic range of field measurement capability and programmable time resolution.

The standard dynamic ranges implemented for the Voyager, ISPM, and Giotto instruments will be utilized for the Mars Global Surveyor. These are:

Max. Field: ±16, ±64, ±256, ±1,024, ±4,096, ±16,384, ±65,536 nT

These dynamic ranges will be switched automatically whenever the ambient field exceeds a predetermined level. The automatic operation mode can be overridden by ground commands. These will be used mostly during the checkout phase. The wide range measurement capability of these instruments is a standard feature of magnetometers developed by our group, and it makes possible their use on a multitude of missions without modification. In addition, since the maximum dynamic range is 65,536 nT, the instruments can be checked out on the ground or in near-Earth orbit without the need for special field-canceling coils or mu-metal shields to attenuate the Earth's field.

The resolution of the measurements is determined by the microprocessor-controlled A/D converter and formatting algorithms. The A-to-D converter to be implemented for the Mars Global Surveyor mission is capable of an ultimate resolution of 16 bits, but it is anticipated that 12 bits will be sufficient for the accomplishment of the major scientific objectives. In the unlikely event that small-amplitude phenomena are detected at Mars, in the presence of a large background field, the on-board software includes an alternative formatting algorithm which allows the acquisition of data at 16-bit resolution by sampling the inboard magnetometer at a much lower rate. The baseline 12-bit resolution leads to the following quantization uncertainties for each dynamic range:

Minimum resolution: ±0.004, ±0.016, ±0.0625, ±0.25, ±1.0, ±16 nT

In the minimum bit rate configuration the outboard magnetometer will be sampled at a rate of 2 samples/s, while the inboard unit will be sampled at a rate of 1 sample/2 s. for an approximate bit rate of 80 bits/s. in the direct readout mode, or 40 bits/s in the 6-bit differencing mode. For the higher spacecraft data rates achievable during different phases of the mission, we intend to adjust our sample rate proportionately, thus yielding a maximum bit rate requirement of 320 bits/s in the 12-kilobit S&E-l format (6-bit differencing mode).

D.2.4 Electron Reflectometer Description

D.2.4.1 Electron Reflection Magnetometry

Electron reflection magnetometry is a technique for remotely sensing planetary magnetic fields with much higher sensitivity and spatial resolution than can be achieved with an orbiting magnetometer alone. Reflection magnetometry depends on the fact that charged particles tend to be reflected from regions of increased magnetic field strength. This fact is also the basis for magnetic mirror machines for the containment of hot fusion plasmas. In a uniform constant magnetic field, charged particles will follow helical paths with constant velocity parallel to the magnetic field and a circular motion perpendicular to the field. If, however, a charged particle enters a region of increasing magnetic field strength, it will experience a force which will tend to decrease the particle's parallel velocity and eventually reflect the particle from the region of increased field. The interplanetary medium is filled with a tenuous plasma (ionized gas made up of electrons and ions) with an ambient magnetic field of typically 5-10 nT strength. When a planetary body is present, the charged particles are guided by the ambient magnetic field to a planetary surface or a particle-stopping height in the planetary atmosphere. If no regions of enhanced surface magnetic fields are present, then the particles are absorbed by the surface or atmosphere, except for <5% which are Coulomb backscattered from surface or atmospheric material. If surface magnetic fields are present, the total field strength increases as the particles approach the region, causing a fraction of the particles to reflect back with an intensity that increases with the strength of the total surface field.

Electrons with energies of a few eV to >20 keV are always present on interplanetary and planetary field lines. These electrons are the ideal charged particles for implementing reflection magnetometry, since they travel at high speed (several thousands of km/s) and have small gyroradii (typically 1 to 100 km). Electron reflection magnetometry from an orbiting spacecraft is illustrated in Figure D-3. As the spacecraft orbits the planet, the region sampled is given by the intersection of the magnetic field line passing through the spacecraft with the absorbing surface. Interplanetary or planetary electrons traveling along the field line toward the planet are usually absorbed, but when a region of crustal magnetization is sampled, a fraction of the incoming electrons are reflected by the increased magnetic field at the surface and can be detected coming back up to the spacecraft.

The technique is based upon the motion of electrons in nonuniform magnetic fields. The equation of motion of a particle of charge q, mass m, and velocity v in a magnetic field of strength B is

$$m\, d^2r/dt^2 = q\, v \times B \qquad (1)$$

where r is the position of the particle. In a uniform magnetic field, the particles move along a helical path of constant pitch angle A and radius R_c, where A is defined as the angle between v and B, and $R_c = mv \sin(A)/qB$. If the magnetic field varies spatially and the fractional change in the field is small over the distance traveled by the particle in one gyration, then the adiabatic approximation holds. It can then be shown that $\sin^2(A)/B$ = constant. Thus, as illustrated in Figure D-4 a particle with pitch angle A_l at a point where the field strength is B_l will travel to a point where the field is $B_m = B_l/\sin^2(A_l)$, mirror there, and return past the initial point with pitch angle Pi-A_l.

If there is an absorbing region below the mirror point, then particles with initial pitch angle A<Al will hit this absorbing region and be lost, while particles with pitch angle A>Al will return past the initial point with pitch angle Pi-A. Thus no returning particles will be observed with pitch angle greater than some cutoff pitch angle A_c = Pi-A_l, except a few (>5%) that are Coulomb backscattered. This "hole" in the pitch angle distribution is called the loss cone. Electron reflection magnetometry is based on the measurement of the size of the loss cone, which gives the ratio of the magnetic field strength, B_s, at the absorbing surface to the field strength, B_l, at the point of observation:

$$B_s = B_1/\sin^2 A_c \qquad (2)$$

The loss cone measurement results in the instantaneous measurement of the ratio of the local magnetic field (provided by the magnetometer) to the field at the point where the local field intersects the atmospheric absorption height for electrons (~120 km for 20-keV electrons). Since the electron absorbing height is ~3 times closer to the surface than the Mars Global Surveyor orbiting altitude, and since the magnetic fields from localized surface anomalies decrease with distance approximately as l/h^3, the ER measurement is made where the anomaly fields are ~30 times larger than at the spacecraft altitude. This remote measurement is much more sensitive to the small martian surface fields, since the overall magnetic field measurements are likely to be dominated by the ambient magnetic field of the solar wind plasma, typically ~5 nT at Mars orbit. Electrons of different energies will stop at different heights in the atmosphere, so measurements over a wide energy range will give the altitude dependence of the field. In addition, photoelectrons produced by solar ultraviolet radiation deep in the martian atmosphere can escape and be detected at the Mars Global Surveyor spacecraft. These electrons will fill a source cone whose angular extent is also given by Equation (2).

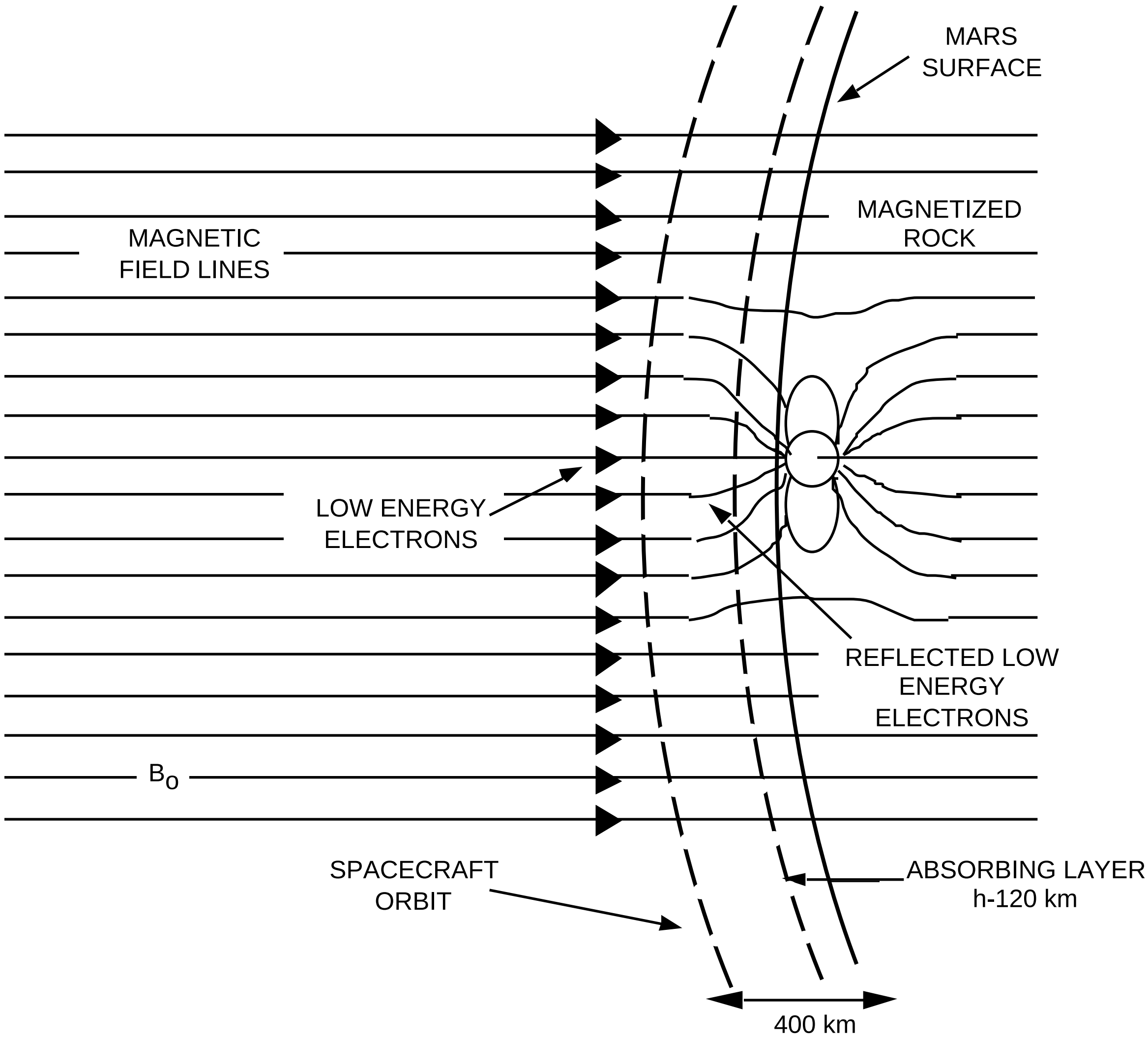


Figure D-3. Electron Reflectometry Geometry

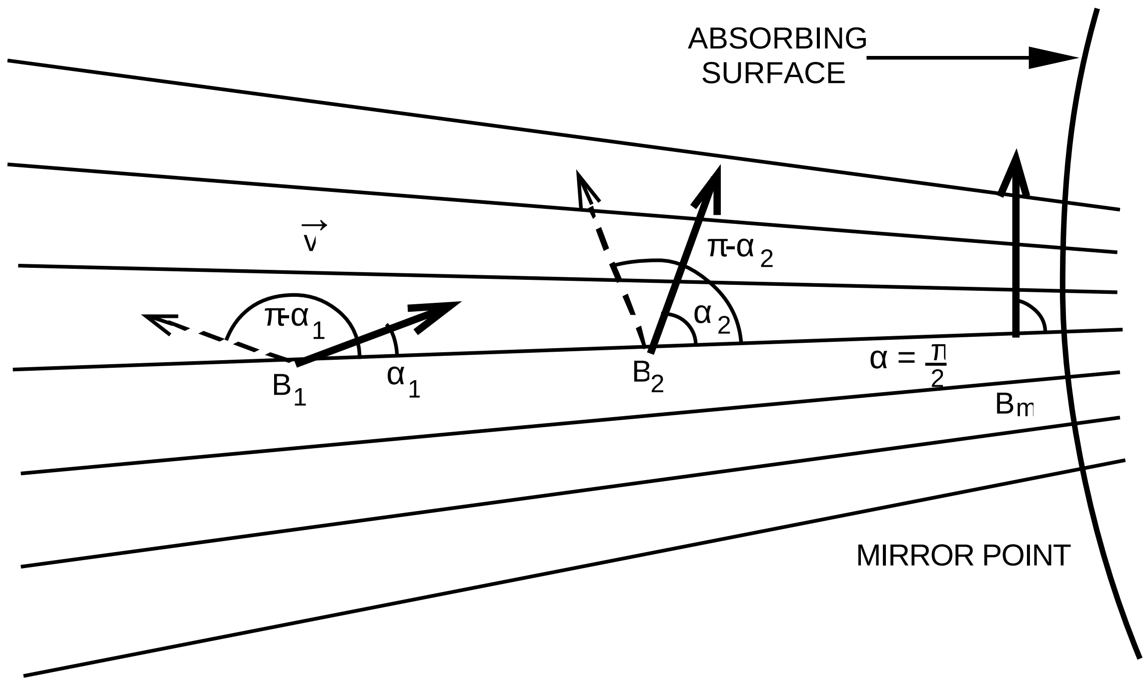


Figure D-4. Loss Cone Geometry

The accuracy of the remote field measurement is determined by the accuracy of the loss cone angle measurement, and the spatial resolution can be as fine as the electron gyrodiameter. Multiple measurements of the same anomaly field with different external fields can also give information about the surface magnetic field direction. Except for very strong surface anomalies, the region sampled is given by the intersection of the extrapolated local magnetic field with the surface. For very strong fields the location of the region can be corrected after mapping.

A major advantage of ER is that a single measurement gives the ratio of the total field strength at the absorbing layer to the field strength at the spacecraft. No averaging or filtering is needed, and the external field needs to be stable only during the measurement, which is obtained in 1 second.

D . 2 . 4 . 2 Instrument Concept

The concept is based on the unique properties of the symmetric hemispherical electrostatic analyzer. The disk-shaped field of view (FOV) of this analyzer uniformly covers a full 360° in a plane and up to ±7° out of the plane. Particles entering the analyzer are focused onto an imaging detector which provides fine angular resolution in the plane of the FOV. Because the analyzer covers a full 360° in a plane, particle pitch angles from 90 - D to 90 + D degrees are sampled, where D is the angle of the magnetic field to the plane of the analyzer's FOV. This situation is ideal, since the maximum sensitivity of the ER method is obtained for detection of reflected particles at pitch angles near 90° (see Equation 2).

D . 2 . 4 . 2 .1 Analyzer Orientation

The plane of the analyzer's FOV will be oriented to include the nadir and be perpendicular to the Mars Global Surveyor's orbital velocity direction. With this geometry the angle of the magnetic field to the analyzer's FOV will always be less than $\sin^{-1}[(R_m / (R_m + 360\text{ km})] = 65°$ whenever the magnetic field points to any part of the planet. Thus, whenever the ER can sample crustal magnetization, the range of pitch angles covered is at least 65° to 115°. This minimum range of pitch angles ensures that the range of magnetic field strengths measured by the ER at the electron absorption layer extends to at least 1.22 B, where B is the field strength at the spacecraft. Increases larger than this are unlikely from a localized source of crustal magnetization, although a strong central dipole could produce such an increase. This analyzer orientation will also place the average interplanetary magnetic direction in the analyzer's FOV and maximize the time that the full pitch angle distribution will be measured.

For the ER to measure planetary magnetic fields, the ambient field must point to the planetary surface. If the ambient field direction were completely arbitrary, then the field line would intersect the electron absorption height in the Mars atmosphere (>120 km) approximately 65% of the time. For a central dipole configuration the field will intersect the planet an even higher percentage of the time. Thus we expect that mapping of crustal magnetization will be possible most of the time.

D.2.4.2.2 Analyzer Data Processing

The analyzer is stepped through 16 energy steps, covering a 0-to-20keV energy range, every second. The analyzer images the particle velocity vectors onto the microchannel plate detector to provide a 1.4° angular resolution in the plane of the detector's FOV. Electron events are sorted by the pulse position analyzer into pitch angle bins and stored in the counter bank. Prior to each energy sweep, the pitch angle bins are computed and updated by the DPU, using the magnetometer's measurement of the local magnetic field direction. After each energy step, the counter's contents are latched and read out by the DPU. Because the volume of data generated by the ER is too large to be transmitted, one of the main tasks of the DPU is to reduce the data to meaningful parameters (loss cone angles, energy spectra, plasma parameters, and averaged distributions) and to format these for synchronous collection. The DPU will perform averages and fits to the data to extract the maximum scientific return.

D.2.4.2.3 Low-Energy Measurements

The instrument design incorporates several features that are needed to accommodate the intense fluxes of low-energy ionospheric thermal electrons and photoelectrons. The total range of electron fluxes spans 11 decades in magnitude and 4 decades in energy. The detector count rate is proportional to energy flux, which can range over 7 decades. In order to maintain good sensitivity at high energies without becoming saturated by the intense fluxes at the low-energy end of the spectrum, the analyzer will include a switchable attenuator that can reduce the geometric factor by 100 for energies below a few hundred eV. The attenuation is accomplished by electrically biasing a grid in the main entrance aperture, which will repel electrons with energies below a few hundred eV. A separate set of small entrance apertures, with an area 1% of that of the main aperture, will bypass the attenuation grid assembly. The attenuation reduces the fluxes of low-energy electrons while maintaining the 1.4° angular resolution.

The analyzer and the local section where the analyzer is attached should be electrically insulated from the spacecraft. This arrangement allows the analyzer to be biased in voltage to keep the instrument near the plasma potential and insure that measurements of low-energy particle energy spectra and angular distributions are not distorted by spacecraft charging.

The low-energy and thermal electron measurements require careful consideration of the spacecraft and ER floating potentials. The spacecraft charges to a potential such that no net current flows between the spacecraft and the plasma. In very low-density plasma, photoemission drives the potential positive a few volts, so that the photoelectrons return to the spacecraft. In a high-density ionospheric plasma, the thermal electron current typically exceeds the ion and photoelectron currents so that the potential goes negative. The magnitude of the potential depends on the ion and electron temperature and mass ratios, but it is typically a few times the electron temperature expressed in eV. The ER and local mounting section will be voltage biased relative to the spacecraft to assure that spacecraft charging does not degrade the low energy electron measurements. Mounting and bias capability are important considerations, particularly in high-density conditions where the potential is likely to become negative.

D.2.5 MAG Data Processing Unit

The current design for the MAG DPU calls for a system with a Harris 80C86 processor and 82C37A DMA controller. A fall-back design will be maintained in case of difficulty with these parts, using two NSC300 or 80C85 parts. The DPU block diagram shows the design of the DPU. The processor clock has been selected to coincide with the BIU clock for simplicity (10.8-MHz crystal, 3.6-MHz processor clock). The DMA clock is also run off this clock. The DMA "cycle-steals" transparently to the processor to transfer data to and from the BIU. (Separate channels are used for sending and receiving data.) The processor programs the DMA with the address to transfer the data to/from. The DMA automatically transfers the data, keeping track of the addresses and word counts. Memory consists of 4 kbytes of PROM (2048 16-bit words) and 8 kbytes of RAM (4096 16-bit words). The RAM requirement includes:

4 x 1 kbyte	Packet buffers (one each for MAG and ER to collect data into, and one each ready to transmit)
1/8 kbyte	Command packet buffer
3/4 kbyte	ER PAD accumulation space (16 E x 16 angle x 24 bits)
1/8 kbyte	Stack 1/2 kbyte Programmable tables, misc. variables
3/2 kbyte	Data collection buffer (FIFO sufficient to collect up to 1 second of raw MAG and ER data while the processor foreground task is busy with computations, command decode, etc.)
1 kbyte	Program modification uplink space, contingency.
8 kbytes	

The RAM does not include space to copy the entire PROM program over. Instead the program will be modularized with modules linked by vectors held in RAM. Individual modules can be modified and uplinked into the "program modifications uplink space," and the vector for that module can be changed to the location of the new, uplinked version. The timing unit generates various clocks for the system from the processor clock generated by the TCU (82C85). About 200 kHz is required for the ER serial interface. The magnetometer clock is also generated. Sector timing is generated by dividing the BIU clock down to as close as possible to 128 Hz. The sector clock is synchronized to the BIU RTI signal (8 Hz) by resetting the divider chain with the RTI rising edge. The 32-Hz MAG sample collection strobe is generated by dividing the 1238-Hz clock and synchronizing to the RTI. The processor interrupt is driven by the 128-Hz signal. The processor then reads the 128-Hz counter contents, to determine the time relative to the RTI, and generates appropriate data collection and instrument control signals.

D.3 Mars Orbiter Camera (MOC)

D.3.1 Investigation Description. The Mars Global Surveyor Camera (MOC) takes pictures of the surface and atmosphere of Mars. Its wide-angle cameras are capable of viewing Mars from horizon to horizon, and are designed for low resolution global and intermediate resolution regional photography. MOC is, however, primarily a telescope for taking extremely high-resolution pictures of selected locations on Mars. The sophisticated electronics (including a 32-bit microprocessor, a high-speed custom integrated circuit for camera control, and a 12-Mbyte frame buffer) provide control of the camera and on-board image editing and buffering to match the spacecraft data system capabilities. The MOC is a "push-broom" camera: it does not take "frames," but rather builds a picture, one line at a time, as the spacecraft moves around the planet in its orbit.

Low-resolution observations can be made every orbit, so that in a single 24-hour period a complete global picture of the planet can be assembled at a resolution of at least 7.5 km/pixel. Of course, because the Mars Global Surveyor orbit is sun synchronous, this global picture shows how each part of Mars appeared at approximately 2:00 p.m. local time. Using the intrinsic resolution of the CCD detectors in the wide-angle cameras, regional areas (covering hundreds of km on a side) may be photographed at a resolution of better than 250 m/pixel at the nadir. Such images will be particularly useful in studying time-variable features such as lee clouds, the polar cap edge, and wind streaks, as well as acquiring stereoscopic coverage of areas of geological interest. The limb can be imaged at a resolution of better than 1.5 km. The two wide-angle cameras have each been optimized for acquisition of a different color, so color images of the surface and atmosphere can be made to distinguish between clouds and the ground, and between clouds of different composition.

Using the high-resolution camera, important areas ranging from 2.8 km x 2.8 km to 2.8 km x 25.2 km (depending on available buffer memory) can be photographed at about 1.4 m/pixel. Additionally, lower-resolution pictures (to a lowest resolution of about 11 m/pixel) can be acquired by subsampling. Contingent upon available power, these images can be much longer, ranging up to 2.8 x 500 km at 11 m/pixel (the cross-track dimension of MOC NA images is fixed at 2.8 km or less).

D.3.2 Scientific Objectives. The objectives of the Mars Global Surveyor Camera are to:

(1) obtain global, synoptic views of the martian surface and atmosphere in order to study meteorological, climatological, and related surface changes during the course of the mission;

(2) examine and monitor surface and atmospheric features at moderate resolution for changes on time scales of hours, days, weeks, months, and years, and at a spatial scale that permits the details of their morphological character to be discriminated; and

(3) systematically examine local areas at extremely high resolution in order to quantify surface/atmosphere interactions and geological processes that operate on short time scales and at extremely small spatial scales. Candidate areas for intensive study include past and possible future landing sites, the layered slopes within the polar terrains, and the migrating edge of the seasonal polar cap.

In practice, these observational objectives fall into two broad science categories: meteorology/climatology and geoscience. Clouds, dust, variable surface features, and wind patterns are part of the former, while observations of morphology of surface landforms (e.g., channels, layered deposits, craters) and their implication for environmental phenomena (e.g., atmospheric debris transport, fluvial processes, etc.) fall within the latter category.

The MOC will acquire images of the surface and atmosphere of Mars for qualitative and quantitative photographic interpretation. The data will be acquired at a variety of spatial resolutions and over a range in time, in order to address questions concerning martian meteorology, climatology, and geoscience. The three main categories of operational modes, types of data to be returned by these different categories, and interpretation and possible anticipated results are discussed below.

D.3.2.1 Global Monitoring

Example observational objectives are to:

(1) monitor global atmospheric phenomena over time scales of days, weeks, months, seasons, and years;

(2) monitor polar cap phenomena over the entire polar region during cap formation, advance, and retreat.

Global monitoring uses the low-resolution capability of the camera to systematically accumulate a global picture of the surface and atmosphere of Mars (Figure D-5). Such a picture can be acquired and transmitted to Earth in one day, thus providing a "snapshot" view of each portion of the planet as seen at approximately 2:00 p.m. local time. These pictures will be very similar to NOAA satellite images of the Earth.

Global monitoring data will be analyzed in much the same manner as terrestrial meteorological satellite images to extract information about atmospheric circulation and water content (from cloud motion and morphology, variable surface features, etc.). Observations will be made sufficiently often to characterize martian global meteorology as a function of season and atmospheric activity.

Examples of anticipated results are:

(1) "weather" maps of the martian atmosphere during the mission;

(2) polar cap boundary maps showing changes as function of season;

(3) correlations with other spacecraft observations.

D.3.2.2 Regional Targeting

Example objectives are to:

(1) observe selected atmospheric phenomena at moderate resolution;

(2) observe changes in selected surface features during the mission;

(3) evaluate the state of Mars relative to earlier missions.

Regional targeting observations will be acquired by the wide-angle cameras to provide higher-resolution, subglobal (regional) views of the surface and atmosphere of Mars. The wide field of view of the system permits daily repeat coverage, if needed, as well as stereoscopic capabilities. The size of the pictures returned is set by the available buffer memory and is selectable over a wide range of along-track and cross-track dimensions. Spatial resolution of these data will be better than 250 m/pixel at the nadir, diminishing to better than 1.5 km/pixel at the limb (making the camera the highest resolution limb-viewing device on the Mars Global Surveyor).

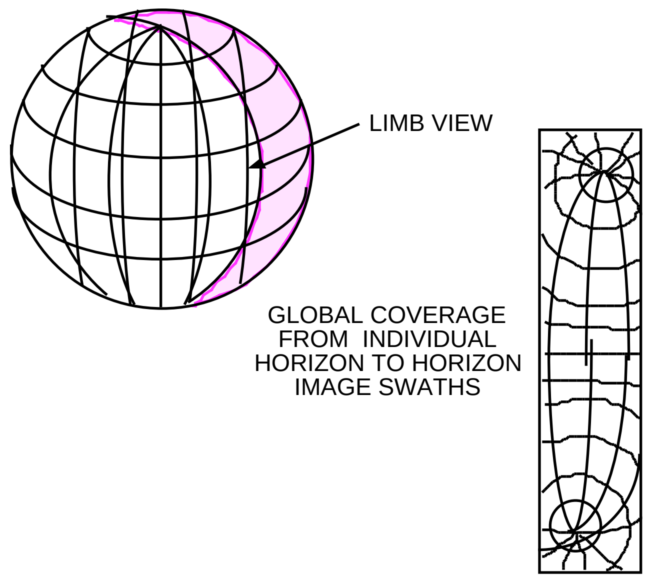


Figure D-5. Mars Orbiter Camera Global and Regional Observations

Two types of targets of particular interest are those to be imaged several times, in a program to monitor changes, and those to be imaged only once, for example, to characterize changes since the Viking mission. Targets to be repetitively imaged will include portions of the polar cap edge (in order to study its rate of advance and retreat, and those factors that influence these rates), dark streaks in Syrtis Major and Amazonis (to evaluate atmospheric dynamical models), and occasional cloud phenomena adjacent to and within the polar hoods. Targets to be imaged only once will include views of limb hazes associated with global dust storms, unusual cloud phenomena of short duration, and many portions of Mars that will likely show albedo changes over the 17 years between Viking observations and those to be made by the Mars Global Surveyor.

In order to discriminate between dust and condensate clouds, observations will be acquired in two different colors. Such observations can occur simultaneously.

Stereo observations can be made on sequential orbits, or pairs can be segregated by one or more 3-day cycles to provide more optimum convergence angles.

Examples of anticipated results are:

(1) characteristics of atmospheric phenomena at better than 0.5-km scale;

(2) evaluation of atmospheric circulation models using variable features;

(3) characteristics of polar cap formation and retreat;

(4) quantified differences between Mars in 1976-80 and 1997-1999;

(5) color images of martian atmospheric and surface features for analysis of differences in cloud type and morphology and surface properties;

(6) derivation of relief from stereo images to determine volumes and potential energy variations of surface deposits and landforms.

D. 3 . 2. 3 High-Resolution Sampling

Example observational objectives are to:

(1) examine surface/atmospheric interactions at high resolution;

(2) study geology at a scale that links Viking Orbiter and Lander data;

(3) observe surface physical properties for use with remote sensing;

(4) evaluate potential Mars landing sites.

High-resolution pictures will be taken through the narrow-angle telescope. The field of view of this telescope is very small, about 0.4° (which translates to about 2.8 km from a spacecraft height of 360 km), and the resolution of the images is about 1.4 m/pixel (depending on spacecraft altitude). This resolution is a compromise between that needed to bridge the gap between imaging observations made by the Viking Orbiter and Viking Lander spacecraft and that possible within the Mars Global Surveyor payload limitations. In order to determine the exact position of the high-resolution pictures, about 500 lines of wide-angle, intermediate-resolution data will be acquired simultaneously with the high-resolution images (Figure D-6) . This "context image" provides the MOC with the unique ability to tell exactly where each picture was taken with respect to the martian surface.

Using the high-resolution camera, important areas ranging from 2.8 x 2.8 km to 2.8 x 25.2 km (depending on available buffer memory) can be photographed at 1.4 m/pixel. Lower-resolution pictures can be acquired by subsampling. Contingent upon available power, these images can be much longer, ranging up to 2.8 x 500 km at 11 m/pixel (the cross-track dimension of MOC NA images is fixed at 2 . 8 km or less) . Power is important because the nominal MOC narrow-angle data acquisition lasts about 5 seconds whereas, for these extended-length images, data acquisition at high power levels could last as long as 170 seconds.

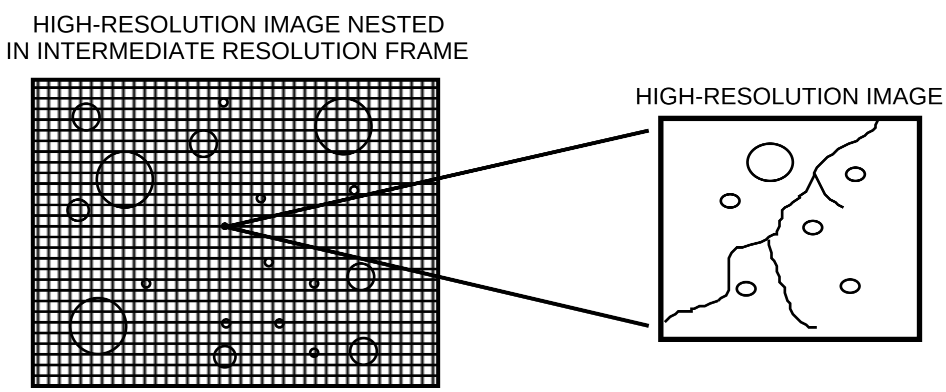


Figure D-6. Mars Global Surveyor Camera High-Resolution Sampling

There are many areas on Mars where such high-resolution pictures will greatly improve our understanding of martian surface processes and the age relationships between various surface features. Of particular interest are the development of the polar caps, the movement of dunes in the polar region, the nature of the polar layered escarpments, the detailed morphology of the channels and valley networks, and the morphology of volcanic features. High-resolution images will be used to determine surface rock abundances in order to help calibrate the remote sensing instruments on the MGS. The Viking landing sites will be observed, and additional pictures of areas of high interest to future landing missions will be acquired.

Examples of anticipated results are:

(1) observations of how the polar caps form;

(2) observations of the movement of sediment/eolian debris;

(3) details of the formation of channels and network valleys;

(4) estimates of the youngest ages of martian terrains;

(5) observation of rock/bedrock/soil ratios;

(6) selection of future landing sites.

D.3.3 Instrumentation. The MOC consists of a single structure, approximately 75 cm in length and 40 cm in diameter, and includes three major components (Figure D-7). Table D-5 outlines the important physical and electronic characteristics of the instrument. The principal component of the camera is the narrow-angle (NA) optics structure, composed of graphite/epoxy. Below the NA mirror is the electronics assembly, housed within the NA structure. Attached to the side of the NA structure are the wide-angle (WA) cameras, consisting of a combined mechanical support and their individual optics and focal planes. The MOC has three sets of optics: two very short focal length "fisheye" lenses and a very long-focal-length telescope. Each has its own CCD line array detector. The camera is fixed-mounted on the nadir panel, pointing down toward Mars; it cannot point itself.

The MOC is a "push-broom" camera, which means that in operation the motion of the spacecraft generates the image by "pushing" the line arrays, oriented perpendicular to the velocity and nadir vectors, along the ground track. The cross-track dimension of the image is defined by the length of each CCD detector, while the along-track dimension is defined by the length of time the detectors are active. The actual ground track velocity will determine the line exposure time. The cameras are electronically shuttered (i.e., the accumulated charges are shifted from the CCD in a fraction of the time required to advance one resolution element).

The NA system is a 35-cm-aperture, 3.5-m-focal-length (F/10) Ritchey-Chretien telescope, filtered to operate in the wavelength band from 500 to 900 nm. A 2048-element line array with 13-µm pixels provides 1.34 m/ pixel at an altitude of 360 km, and better than 1.5 m/pixel over the entire range of operational altitudes. The WA system consists of two f/6 11.3-mm focal-length fisheye lenses, one optimized in the band from 400 to 450 nm and the other in the band from 575 to 625 nm. A 3456-element line array with 7-µm pixels provides a nadir resolution of 230 m/pixel in the red and 225 m/ pixel in the blue from an altitude of 360 km.

The electronics consists of a 32-bit microprocessor operating at 10 MHz and 1 MIPS, a 12-MB buffer consisting of 1 Mbit (Mb), 120-ns RAM, two 11,000-gate application-specific integrated circuits (ASICs). These particular ASICs are critical points (e.g., gate arrays, A/D converters, microprocessors). The functional block diagram is shown in Figure D-8.

Several specific measurement objectives were considered most important in designing the MOC. Two objectives drive the optical designs: (1) narrow-angle images must have an average resolution of 1.4 m/pixel or better, based on a variety of factors, and (2) the wide-angle field of view must extend from limb to limb, with approximately 80 km margin at each limb.

The 1.4-m/pixel value comes from assessment of observational objectives likely to provide diagnostic information on geological phenomena of extreme interest. These include:

(1) the search in the polar layered terrains for layers smaller than those resolved by Viking and Mariner 9;

Table D-5. MOC Performance Parameters

Narrow-Angle Assembly	
Focal Length	3.5 ±0.035 m
Focal Ratio	f/10 ±1
Aperture	0.35 ±0.0035 m
Angular Field of View	7.7 ±0.38 mrad
Instantaneous FOV	3.7 ±0.04 mrad
CCD Readout Noise	<100 electrons at -20°C
Signal-to-Noise Ratio	20:1 for A~0.l, i~70°, at aphelion
Radiometric Accuracy	10% absolute, 3% relative
Spectral Band	500 nm to 900 nm
System MTF	>0.1 at all frequencies below Nyquist
Wide-Angle Assembly	
Focal Length	11.3 ±0.05 mm
Focal Ratio	f/6.5 ±0.5
Angular Field of View	2.44 ±0.005 rad
Instantaneous FOV	0.72 ±0.04 mrad
CCD Readout Noise	<300 electrons at -20°C
Signal-to-Noise Ratio	20:1 for A~0.l, i~80°, at aphelion in the 400-nm to 450-nm band; 20:1 for A~0.l, i~85 at aphelion in the 575-625-nm band
Radiometric Accuracy	10% absolute, 3% relative
Spectral Bands	400 to 450 nm and 575 to 625 nm
System MTF	>0.1 at all frequencies below Nyquist
Electronics Assembly	
Processor	>0.5 MIPS
Software	
Compression	3:1 ratio for lossless compression; >10:1 with loss
Error Encoding	<10-4 bit error rate for all returned images, based on Reed-Solomon encoding of S/C data

(2) the assessment of sediment transported during channel-forming events (several phenomena have power-law and log normal boulder size-frequency relationships that can be differentiated at resolutions of less than 2 m/pixel);

(3) the search for landforms diagnostic of ground water or ground ice processes (also in the 2-m/pixel size range); and

(4) characterization of the Viking Lander sites at a scale that permits Lander and Orbiter images to be compared.

This last objective requires that sufficient targeting capability and ground track spacing control be exercised to acquire images of both Viking Landers (see paragraphs 3.2.3 and 4.4.3).

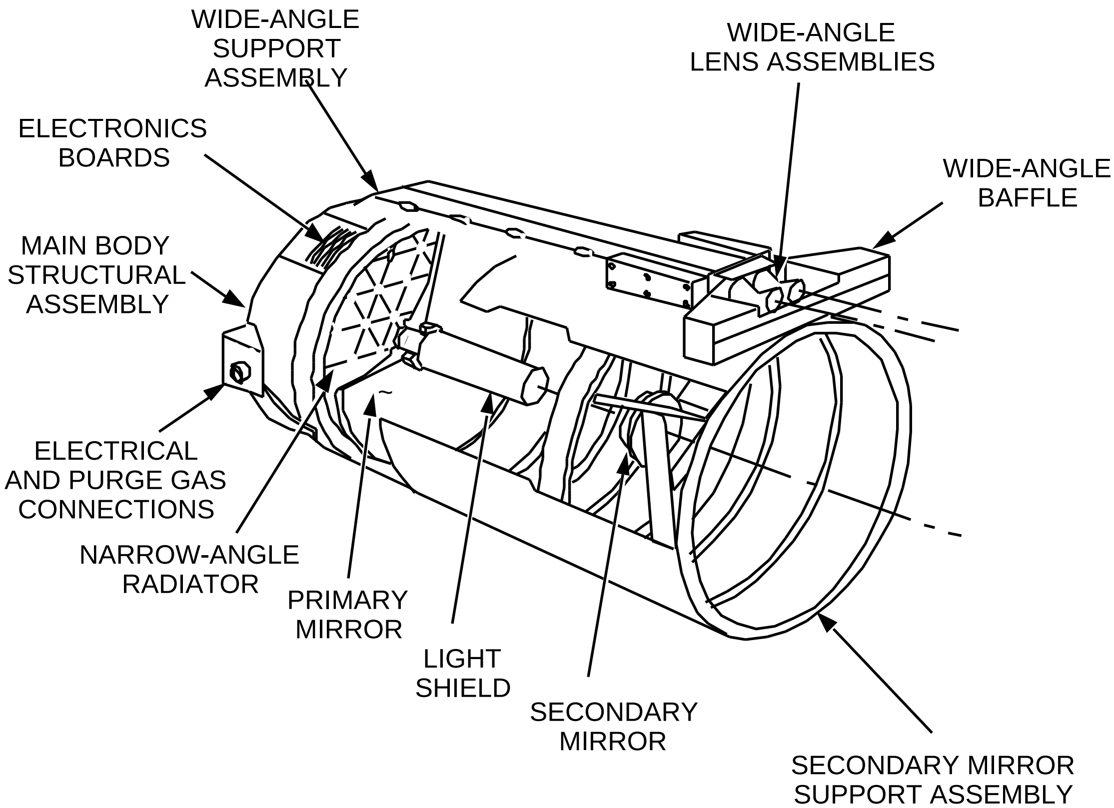


Figure D-7. Mars Orbiter Camera

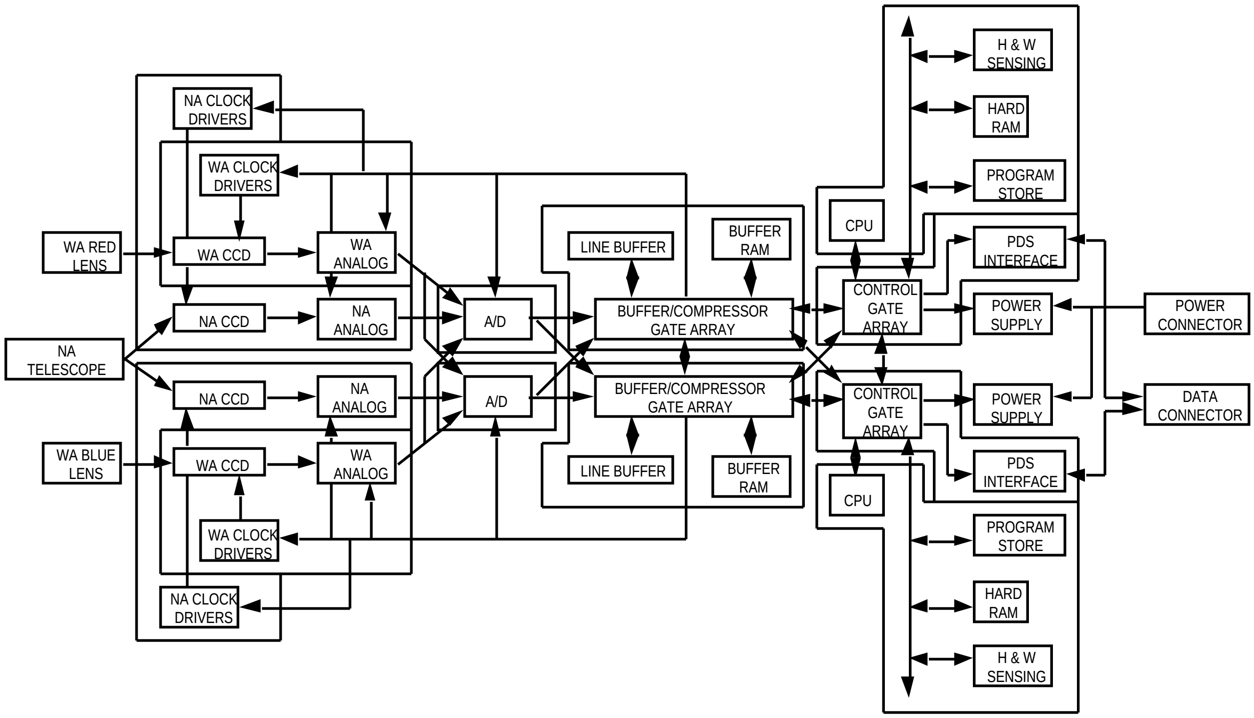


Figure D-8. MOC Block Diagram

In order to interpret MOC images, a minimum signal-to-noise ratio (SNR) of 20:1 is required for a narrow-angle target of albedo (A) = 0.10 at an illumination angle (i) of 70°, and a wide-angle target of A = 0.10 at i = 85°. In order to achieve the required spatial resolutions of 1.4 m/pixel (narrow angle) and 250 m/pixel (wide angle), the system modulation transfer function must exceed 0.10 at all spatial frequencies below the Nyquist limit.

D.4 Deleted

D.5 Mars Orbiter Laser Altimeter (MOLA)

D.5.1 Investigation Description. The primary objectives of this investigation are: a) the determination of the global topography of Mars at a resolution suitable for addressing problems in geology, geophysics, and atmospheric circulation. b) the determination of the 1.06-µm reflectivity of Mars at a resolution suitable for contributing to analyses of global surface mineralogy is a secondary objective. The information that will be supplied by this investigation is crucial for addressing a wide range of scientific questions, a number of which are outlined below.

D.5.1.1 Geodesy. The absolute accuracy of present knowledge of surface locations on Mars is generally on the order of 1 to 2 km radially from the planet's center of mass and 1 to 3 km horizontally. The quality of positional knowledge is highest within 30 degrees of the equator and deteriorates rapidly toward the poles. The reference surface for elevation has an uncertainty with respect to the geometric center of the planet of ±1.0 km. From the Mars Global Surveyor, simultaneously derived topography and gravity field models will be obtained which will permit the derivation of a global geodetic control grid for the planet on a scale of 3 km. The accuracy of this grid is anticipated to be on the order of 30 m radially and 300 m horizontally. Given this, it should be possible to confidently establish absolute positions within the high-resolution MOC images, which is of great importance for assessing future Mars landing sites. In addition, because the gravity and topography will be referenced to the same center-of-mass coordinate system, it will be possible to derive very accurate regional and global topographic gradients that could be used to address a variety of problems in geology, geophysics, and atmospheric circulation, such as those discussed below.

D.5.1.1.1 Internal Structure and Global Tectonics. Current understanding of the interior of Mars is limited to broad generalizations. Such important factors as the thickness of the crust and thickness and isostatic state of the lithosphere are poorly known. These fundamental parameters can be determined through studies of the power spectral relationships between gravity and topography, and by analysis of flexural displacements due to surface loads such as major volcanoes. The thickness of a planet's lithosphere is to a large extent a function of the internal thermal structure. Results derived from current data suggest that on average the martian lithosphere is much thicker than that of Earth, indicating that Mars topography is required to resolve regional variations in lithosphere thickness that may be associated with processes such as mantle thermal anomalies, volcanism, or major impacts. Analysis of flexure of the polar caps could provide constraints on the viscosity of the martian mantle, which is of key importance in understanding the manner by which heat is lost from the interior.

Several fundamental problems relating to the global tectonics of Mars remain unsolved. Superimposed on the northern lowlands of Mars is the Tharsis plateau, a 10-km-high region that occupies a quarter of the surface area of the planet and has dominated its recent tectonic history. With the present topography, models for the origin of Tharsis cannot distinguish whether the elevation is primarily a consequence of mantle uplift or of volcanic construction. With improved topographic resolution it should be possible to assess the relative contributions of these mechanisms. Another first-order question is the origin of the hemispheric dichotomy, a distinct (~3 km) and, in many places, abrupt elevation difference between the rugged cratered highlands in the south and the smooth, sparsely cratered lowlands in the north. This dichotomy reflects a global-scale resurfacing event of unknown origin. Crustal dichotomies are also present on the Earth and Moon, and are generally interpreted in terms of compositional and lithospheric thickness variations. Improved topography may permit the distinction between models of formation due to endogenic (e.g., subcrustal erosion) and exogenic (impact) mechanisms.

D.5.1.1.2 Stress Field. The stress field within the outermost layers of a planet, the effects of which can be observed in large-scale fracturing and faulting, can provide insight into its internal processes and tectonic history. Both detailed topography and gravity are needed to understand the nature of this stress field. Stresses may arise due to global scale processes such as planetary thermal expansion/contraction and convection, or from regional effects such as a volcanic load. Topography will provide a key constraint on models to distinguish between global and regional mechanisms. In addition, better topography will yield information on the manner in which the martian stress field changed through time. For example, topographic profiles across extensional and compressional tectonic features of a given relative age will permit a direct estimate of the magnitude and distribution of strain associated with a given tectonic episode. Spatial and temporal refinement of the stress field will provide insight into the thermal and tectonic history of Mars, and permit detailed comparisons with Earth, Venus, and the Moon.

D.5.1.1.3 Surface Processes and Volatiles. Virtually all geologic processes involving flowage of materials require knowledge of topography and topographic gradients. The dynamics of erosional processes on Mars involving wind, water, and ice are essential in the development of models of global martian climatic cycles. Key questions related to the physics of surface processes typically are concerned with regional slopes on baselines of tens of kilometers or less. For example, to resolve basic questions relating to whether slope control of mass-wasting is significant on Mars (especially in areas of low relief), a high-integrity global topographic model is necessary. Together with precise regional slopes, a knowledge of parameters including heights, widths, depths, rim heights, etc., of fundamental landform types such as grabens, ridges, channels, and craters permit quantification of landform degradation as a means of understanding past climates. For many geologic process-related problems, elevation data together with derived slopes can be used in conjunction with morphology determined with global imaging data sets to place constraints on the formation, emplacement, and degradation of diagnostic landforms and landform assemblages. For example, the intensity and net effect on the surface of regional eolian processes is strongly controlled by both slopes and major topographic obstacles; if large enough obstructions to near-surface flow exist, certain deposition patterns will develop. Wind tails, moats, and other phenomena depend on the nature of the obstruction in the windstream, and may develop in a given location only during specific martian climatic conditions.

Quantification of slopes and gradients will enable the identification of possible source regions for the ancient channels. Topographic characterization of the geometrics of channels will assist in the distinction between formation due to water, ice, or water-ice mixtures, and will therefore provide important information on martian paleoclimates and hydrologic cycles. For example, there is a set of channels that may have been formed by catastrophic release of water; regional slopes could be used to confirm or refute this hypothesis. Determination of slopes and basins in ancient terrains could be used to identify areas where liquid water may have ponded early in martian history. A dense topographic grid in the polar regions will make it possible to accurately estimate the thicknesses and volumes of the polar caps and the associated layered deposits and thus better constrain the present volatile inventory.

D.5.1.2 Volcanism. An accurately registered topographic grid will permit quantitative assessment of volcanic flow volumes and gradients, allowing an estimate of the yield strengths and effective viscosities of magmas. Such information allows insight into eruption rates, magma compositions, flow dynamics, and the depths of magmatic source regions. This in turn will contribute to a better understanding of the spatial and temporal thermal structure of the Mars interior and the history and extent of chemical differentiation. Quantitative analyses of the shapes of volcanic craters may help identify areas in which volatiles were present at the time of eruption.

D.5.1.3 Impact Cratering. Major impacts significantly perturb the thermal and mechanical state of the lithosphere and must have played a significant role in the early evolution of Mars. The subsurface structure associated with an impact basin, as determined by topography and gravity, provides a basis for determining the depth of excavation and amount of rebound associated with the impact and the extent of the thermal perturbation of the mantle. This will yield insight into the importance of large impacts relative to internal dynamics in contributing to the early head budget of Mars. The topographic shapes of impact craters and basins are sensitive indicators of the depth distribution of mechanical strength, and can be used to constrain fundamental properties of the martian interior such as the thermal gradient and crustal layering and thickness. Impact crater morphology, especially for pristine simple crater forms, provides important constraints on the mechanics of the cratering process as a function of target properties and gravity.

D.5.1.4 Atmospheric Circulation. Surface topography is a necessary lower boundary condition in models of atmospheric circulation. On a regional scale, such models provide information on winds and near-surface wind stresses that will be needed to assess future landing sites. On a global scale, elevation data are required to quantify topographic asymmetries between the poles that influence quasi-periodic climate changes. Better topography is also required to understand the influence of buoyancy waves in global atmospheric dynamics. Buoyancy waves, which form in the atmosphere above regional topographic highs, significantly perturb zonal winds and may relate to the pole-to-pole reversal of the atmospheric temperature gradient.

D.5.1.5 Synergistic Studies. Global topographic data is synergistic with multispectral imaging data sets, with potential field (gravity and magnetic) data, and with data pertaining to atmospheric phenomena. In this regard, the Mars Orbiter Laser Altimeter will provide a unique database from which to make detailed comparisons with other instrument observations. As an example, critical questions concerning the composition of the martian surface will be addressed by thermal emission spectroscopy; geologic interpretation of these data will require consideration of slope, aspect, and elevation effects. Analysis of combined topography and gravity provide the only direct means of discerning the internal structure of Mars. In improving global circulation models of the martian atmosphere, topographic elevations and slopes must be related to spatial changes in atmospheric thermal structure and zonal wind patterns. Many other key issues in Mars geoscience involve interdisciplinary investigations of the interactive processes among the lithosphere, cryosphere, and atmosphere, and many of these fundamental processes are dependent on absolute elevation, relative relief, or surface slope.

D.5.2 Measurement Objectives. The Mars Orbiter Laser Altimeter investigation will:

(1) Provide a precise measurement of the distance from the satellite to the martian surface, which, when subtracted from the spacecraft's ephemeris, will produce a high-resolution topographic profile along the sub-satellite track at a sufficient vertical and horizontal resolution to study both a range of problems in geology, geophysics and atmospheric circulation..

(2) Provide active 1.06-µm surface backscatter measurements which can be related to the global surface near-infrared reflectance, and which will contribute to the characterization of the martian surface compositions.

The Mars Orbiter Laser Altimeter (MOLA) depicted in Figure D-9 is a pulsed laser ranging system with a 1.6-~m wavelength; Figure D-10 shows a functional block diagram of the MOLA. The altimeter has a nominal footprint diameter no larger than 100 m. The vertical precision, when the martian terrain has a slope of less than 2 degrees (or a height variation of less than 6 m) across the footprint, will be approximately 2 m. Figure D-11 shows a characterization of this performance as a function of surface slope. The absolute accuracy of the height measurement, which is limited by the accuracy to which the spacecraft position is known, is expected to be about 30 m over the entire planet. Precision orbits required to realize this objective will be derived by the MOLA investigation using the gravity field provided by the Radio Science Investigation. These precision orbits will define the position of the spacecraft in the Mars center of mass coordinate system to an accuracy of about 30 m vertically and 300 m horizontally.

In summary, the quantities to be measured are:

(1) Topographic height with a vertical resolution of roughly 10% the elevation change within the footprint. This precision varies from 2 m over flat terrain (slope <1°) to about 10 m where surface tilts are large (>12°).

(2) Active surface reflectance at 1.06 µm, as derived from the ratio of received to transmitted laser pulse energy.

Based on the above measurements, MOLA will provide:

(1) Topographic profiles along the spacecraft ground track with a relative vertical precision of 2-20 m and an along-track sampling interval of approximately 330 m.

(2) Globally gridded topographic data sets with a vertical accuracy of about 30 m and grid spacings ranging from 0.5° after one complete mapping cycle to approximately 0.2° (depending on orbit coverage) at the end of mission.

(3) Surface 1.06-µm reflectivity profiles along the spacecraft ground track with a precision of 10% and an along-track sampling interval of approximately 330 m.

(4) Globally gridded 1.06-~m reflectivity data sets with an accuracy of 10~ and grid spacings ranging from 0.5° after one complete mapping cycle to approximately 0.2° (depending on orbit coverage) at the end of mission.

D.5.3 Instrumentation. Figures D-9 and D-10 and Table D-6 describe the altimeter system, including engineering data on size, mass, and signal parameters.

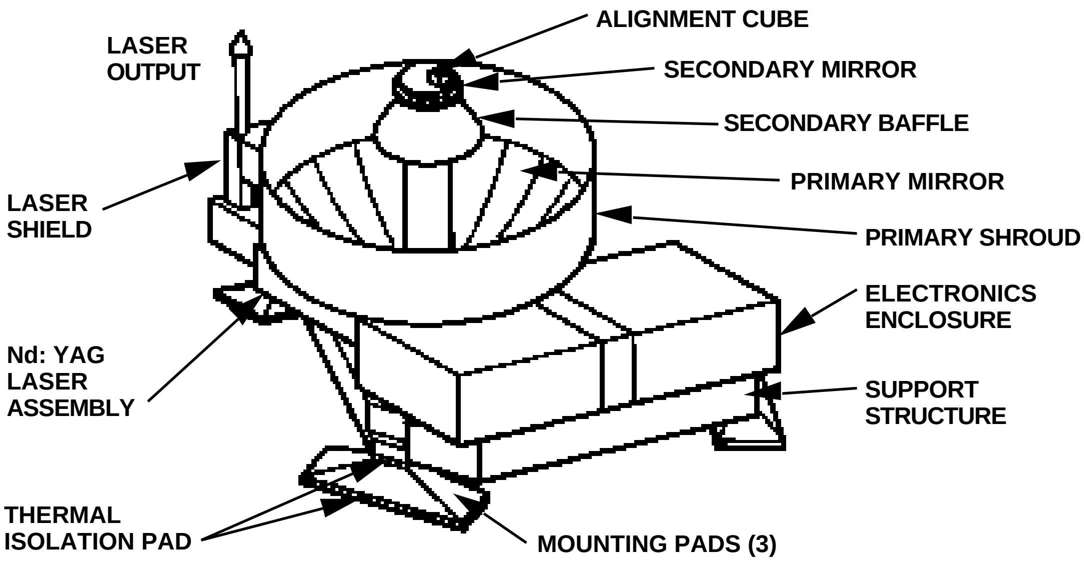


Figure D-9. Mars Orbiter Laser Altimeter

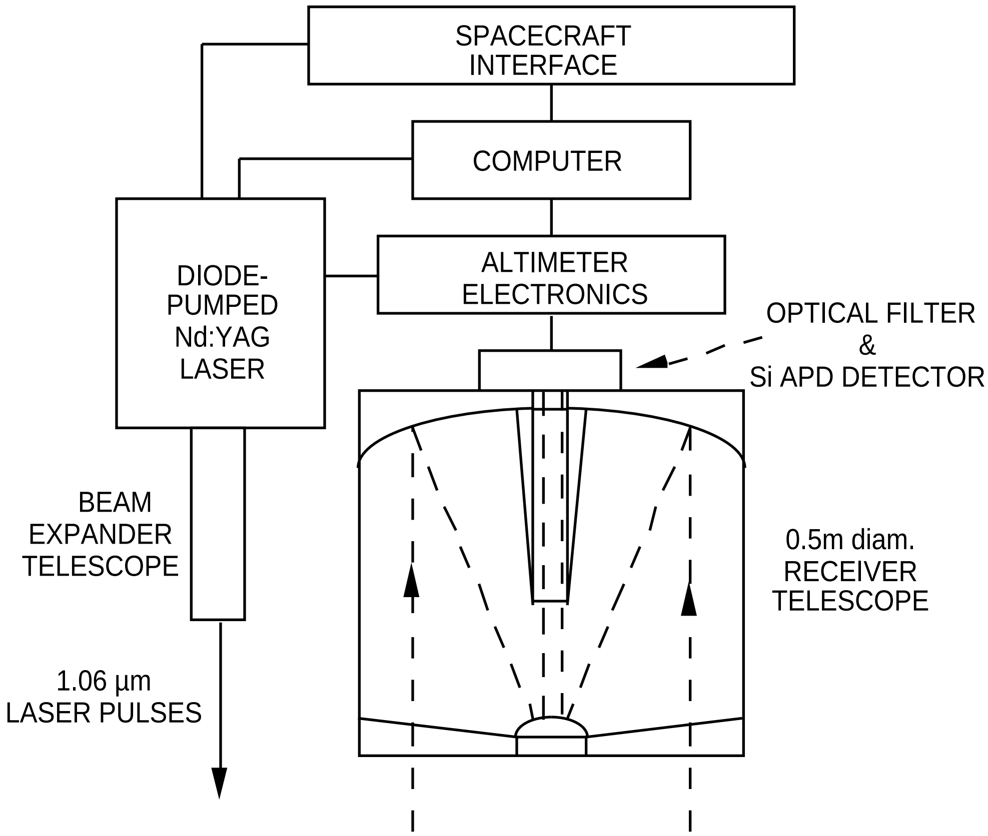


Figure D-10. Laser Altimeter Block Diagram

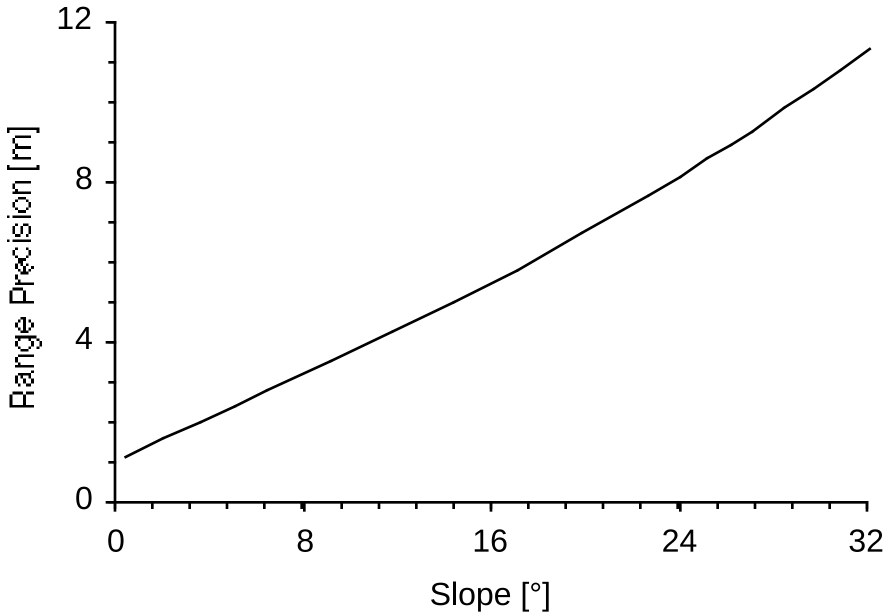


Figure D-11. MOLA Performance as a Function of Surface Slope

Table D-6. MOLA Engineering Parameters

Physical characteristics	
Mass:	25.9 kg maximum
Diameter:	70 cm
Height:	50 cm
Power consumption:	23.7 W + 10 W on-orbit heater
Laser Transmitter	
Type:	Diode-pumped, Q-switched Nd-YAG
Wavelength:	1064 nm
Pulse energy:	30-45 mJ
Pulse width:	~10 ns @ half-maximum
Repetition rate:	10 Hz
Beam diameter:	2.5 cm x 2.5 cm (square near-field)
Beam divergence:	0.25 mrad
Lifetime:	10E9 shots minimum
Altimeter Receiver	
Type:	IR-qualified Cassegrain telescope
Aperture:	50 cm
Focal length:	74 cm
Mirror composition:	Gold-coated beryllium
Detector:	Silicon avalanche photodiode
Sensitivity:	1 nW
Optical filter:	2.0-nm low-passband
Receiver Electronics	
Type:	Match-filtered leading edge tracker
Time resolution:	10 ns
Pulse energy resolution:	10%

D.6 Radio Science (RS)

D.6.1 Investigation Description. Radio occultation and tracking experiments carried out with the Mars Global Surveyor will advance two fields fundamental to the study of Mars and, more generally, planetary science. First, radio occultation observations of the polar atmospheres will provide consistent, accurate, long-term monitoring of seasonal (and shorter) variations of the total gas content and vertical structure of the neutral atmosphere, including the atmosphere's response to opacity loading during dust storms. Vertical profiles of atmospheric refractive index, number density, temperature, and pressure will be obtained over the lowest several scale heights at a vertical resolution of about 200 m, with the possibility of obtaining very fine resolution (to 10 m) in the boundary layer near the surface. These radio occultation profiles will complement and extend other types of Mars Global Surveyor atmospheric observations in that they offer the potential for superior accuracy and vertical resolution and can be obtained reliably in a dusty atmosphere. In addition, it may also be possible to characterize the main ionospheric layer. Signal scintillations, if detectable, will be studied to extend our understanding of small-scale dynamical processes.

Second, radio tracking of Mars Global Surveyor will provide improved information on the structure of Mars gravitational field through measurement of its effect on spacecraft motion. The much lower average altitude of Mars Global Surveyor (as compared with Mariner 9 and the Viking Orbiters) plus planned improvements to the radio subsystem will yield unprecedented global coverage, spatial resolution, reliability, and accuracy in the derived gravitational field model. These data will permit parameter estimation of Mars' internal structure and inferences of the planet's evolution.

In addition, from the analysis of the orbital evolution of the Mars Global Surveyor spacecraft it is anticipated that an estimate will be obtainable for the orbital decay due to air drag. This estimate will provide a value for the average air density at the orbital altitude, averaged over a period of several days. This measure of the density can be used as an upper boundary level value in modeling of the martian atmosphere.

In both the atmospheric and gravity studies it is expected that there will be close cooperation with other Mars Global Surveyor experiment teams. For example, the radio occultation profiles will be interpreted within the context of global models of the martian atmosphere and climate through joint work with scientists using other sounding instruments and with theorists. Similarly, the gravity results will be interpreted in conjunction with topographic data obtained from the altimeter.

D.6.2 <u>Science</u> <u>Objectives</u>. Specific scientific objectives are:

For the atmosphere -- (from radio occultation data):

(1) To determine profiles of refractive index, number density, temperature, and pressure at the natural experimental vertical resolution (~200 m) for the lowest few scale heights of the martian atmosphere at high latitudes in both hemispheres on a daily basis.

(2) To monitor both seasonal and shorter term variations in the vertical structure of the atmosphere with emphasis on the seasonal cycling of carbon dioxide caused by the alternating pattern of condensation and sublimation at the poles.

(3) To characterize the thermal response of the atmosphere to dust loading during the genesis, evolution, and decay of both local and global dust storms.

(4) To explore the thermal structure of the atmospheric boundary layer (adjacent to the surface) at very fine vertical resolutions (~10 m) with emphasis on the interaction between the atmosphere and surface materials (ice and dust).

(5) To search for and to characterize longitudinal variations in the temperature-pressure profiles, such as those associated with traveling baroclinic waves.

(6) To determine the height and peak plasma density of the daytime ionosphere and to investigate the interaction of the solar wind with the atmosphere and magnetic field of Mars.

(7) To characterize the small-scale temperature structure and dynamics of the atmosphere and the small-scale electron density irregularities of the ionosphere.

For the gravity field -- (from radio tracking data):

(1) To produce high-resolution line-of-sight gravity maps (i.e., contour maps of near-vertical gravity superimposed on Mars' topography);

(2) To develop a global, high-resolution model for the gravitational field of Mars by estimating spherical harmonic coefficients through degree and order 30 to 50 and/or characteristics of gravity anomalies;

(3) To detect and quantify temporal changes in low-degree harmonics of the gravitational field due to seasonal variations in the polar caps and atmosphere;

(4) To determine the power spectrum of the gravitational field;

(5) To map the geoid height, gravity anomalies, and associated errors;

(6) To combine gravity and topography data from Bouguer gravity maps, Isostatic Anomaly maps, and the admittance function of the gravitational field;

(7) To estimate (in conjunction with altimetry) both the local and broad-scale density structure and stress state of the martian crust and upper mantle;

(8) To test various geophysical theories by comparing the observations with predictions derived from models of internal structure;

(9) To infer planetary evolution from the modeling results;

(10) To improve the mass estimate of Phobos.

For the upper air density -- (from orbital decay data):

(1) To determine the variation in air drag on the MGS spacecraft throughout the lifetime of the mission.

(2) To estimate the average density of the martian atmosphere and its time variation at 360 to 400 km from the drag measurements.

(3) To characterize the variation in the density of the martian upper atmosphere in terms of local time, latitude, solar activity, etc.

D.6.3 Measurement Approach. Before discussing the specific measurement objectives for the atmospheric and gravitational aspects of the Mars Global Surveyor Radio Science Investigation, we first give an overview of the experimental equipment both onboard the spacecraft and at the NASA Deep Space Communication Complexes (DSCCs) and of the experimental geometry. This will serve to introduce the reader to the distributed nature of the Radio Science experiments, and will provide background for the more specific discussion of the performance requirements for the equipment given in subsequent sections.

The relevant equipment aboard the spacecraft is shown schematically in Figure D-12; the intimate connection with the general telecommunications equipment is apparent. Figure D-13 shows a trajectory-plane view of a "typical" orbit in the mapping phase of the mission. Investigation of the martian gravity field will be conducted in the usual "two-way" tracking mode where the downlink signal from the spacecraft is coherently related to the uplink signal from the DSCC. However, the time required to establish this two-way link upon emersion from occultation exceeds the event time of the atmospheric occultation experiment; hence, this configuration is unacceptable for the atmospheric investigation. Instead, the signal transmitted by the spacecraft should be referenced to the onboard ultrastable oscillator (USO), and both telemetry and ranging modulations should be switched off to maximize the power in the X-band carrier during occultation observation periods. Although this "one-way" configuration is strictly necessary only at emersion, it is requested during all occultation experiments in order to provide uniform data at both occultation immersion and emersion.

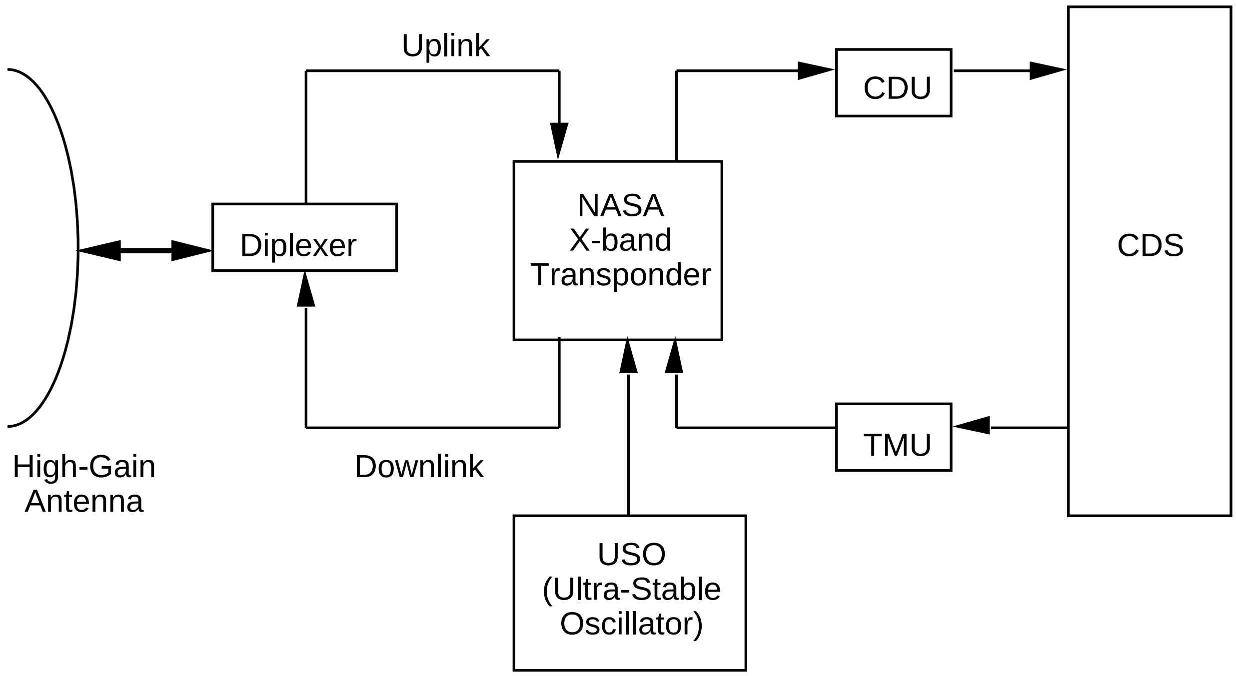


Figure D-12. Mars Global Surveyor Spacecraft Telecommunications and Radio Science Equipment.

The capability should exist to command the frequency of the downlink signal to be referenced either to the uplink signal or to the USO, as required for Radio Science Experiments. In addition, it should be possible to command telemetry and ranging modulations to be turned off.

Figure D-14 shows a schematic of the Radio Science equipment at the DSCC along with the communication links to the Mars Global Surveyor Project Data Base and the Radio Science Team. It is important to note that separate systems exist for recording data from the atmospheric and gravitational experiments; both data types shall be delivered electronically to the Project Data Base where they will be accessible to Radio Science Investigators through Project-supplied Work Stations (Section 7.2). Prior to the radio occultation experiments, the Mission Operations System (MOS) shall provide orbit ephemeris predictions to the Deep Space Network (DSN) for use in acquiring the data (see Section 4.8).

Other specific measurement objectives for the atmospheric and gravitational aspects of the Mars Global Surveyor Radio Science Investigation are quite distinct and are discussed separately.

D.6.3.1 <u>Atmospheric</u> <u>Measurements</u>. Radio occultation experiments require proper configuration of the spacecraft equipment to optimize the characteristics of the emitted signal during the occultation intervals. At the same time, the Radio Science System and operational procedures at the DSCCs must be designed to ensure reliable and accurate acquisition of unique data. Calibration data are required from both the spacecraft and the DSN stations to support the analysis and interpretation of the occultation measurements.

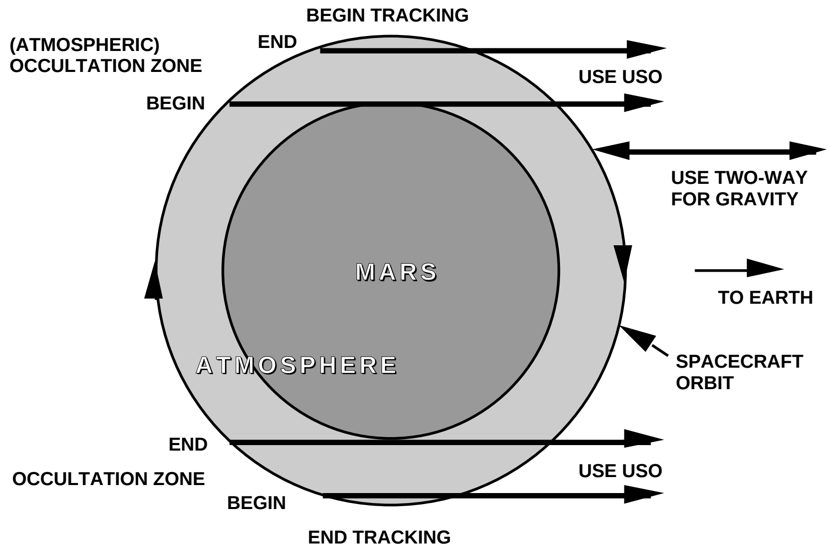


Figure D-13. Trajectory Plane View of the Orbit at Mars

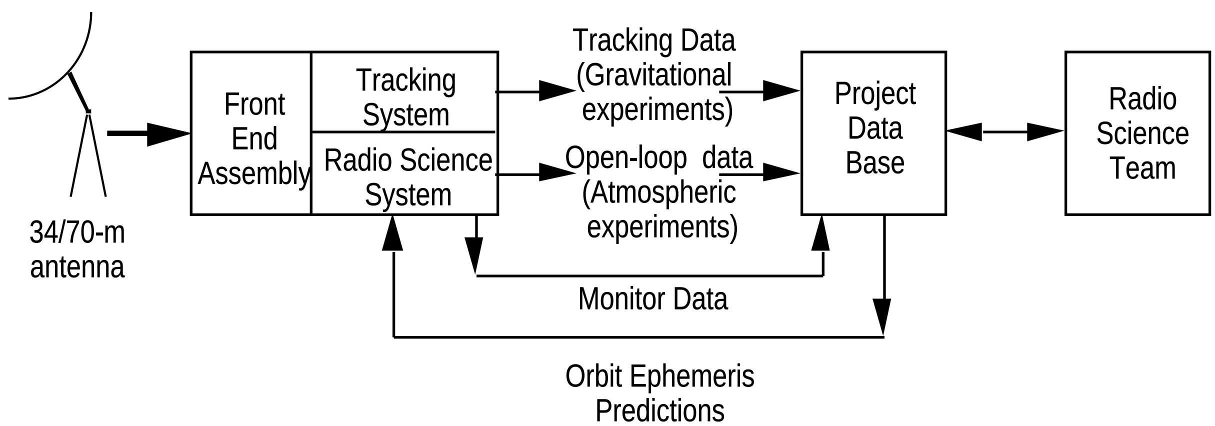


Figure D-14. RS Ground Equipment Interconnections

The mapping phase of the Mars Global Surveyor Mission includes Earth occultations during most of the 116-minute orbits, with immersion and emersion generally at high southern and northern latitudes. (Exceptions occur late in the mission when the occultation latitudes converge toward the equator, followed by an interval of about 30 days during which occultations are absent.) Planned tracking of the Mars Global Surveyor spacecraft is currently limited to one pass of a 34-m DSN antenna each day, with a 70-m antenna available every third day. All occultations that fall within each pass allocated to Mars Global Surveyor should be observed and recorded; this encompasses about four occultation immersion/emersion pairs per day. By recording multiple sets of occultation data from within a single pass of a DSN station, we can derive a family of vertical profiles of the atmospheric structure on Mars at each of two latitudes (typically about 70°N and 70°S) with relatively high time resolution. Due to Mars' rotation, each family of profiles would sample atmospheric conditions at a range of longitudes. This strategy offers a number of advantages for the Mars Global Surveyor Mission, including:

(1) higher probability of sampling atmospheric conditions during local dust storms;

(2) increased flexibility to achieve experimental objectives in spite of the presence of local gravitational anomalies on Mars, which can introduce a serious bias into the profiles derived near certain locations;

(3) substantial improvement (through repeated independent sampling) in the accuracy of certain key results, such as the surface pressure and total gas content of the atmosphere;

(4) the possibility of observing longitudinal variations in pressure and temperature such as those associated with traveling baroclinic waves;

(5) greater tolerance to malfunctions in the ground system for data acquisition.

We emphasize that no additional hardware or software for data acquisition and analysis is required to extend the observations from one to several occultations per pass.

During each radio occultation experiment, the X-band signal received from the spacecraft shall be heterodyned to baseband in open-loop receivers and samples of the signal shall be coherently recorded in digital form on some suitable storage medium (for specific requirements, see Section 4.8). The atmospheric investigator will process these data using established techniques to yield surface pressure as well as vertical profiles of atmospheric structure. In addition, new algorithms for data reduction will be developed and applied to correct for diffraction effect, thereby providing profiles at extremely fine vertical resolution. We emphasize that the derived atmospheric profiles are susceptible to a bias due to errors in knowledge of spacecraft trajectory. Accordingly, accurate knowledge of the trajectory, and hence of Mars' gravitational field, is required for this investigation.

The same occultation data used for study of vertical structure can be processed to obtain scintillation parameters needed for study of small scale temperature structure and atmospheric dynamics. In this case the data processing algorithms are designed to extract the statistics of the signal fluctuations relative to the mean signature of the atmosphere and, possibly, the ionosphere. The radio scintillation measurements will yield information on the intensity (including its variation with altitude) and spatial wavenumber spectrum of the refractive index and temperature irregularities covering scales of the order of the Fresnel size (about 0.4 km) and smaller. In case ionospheric scintillations are detected, the intensity and spatial wavenumber spectrum of the electron density irregularities will be measured.

D.6.3.2 Gravitational Measurements. In developing a high-resolution gravity model, the gravitational field will be described by spherical harmonics, local functions representing high-frequency anomalies, and combinations of the two. The spherical harmonic representation could possibly be extended to degree and order 50, corresponding to a half-wavelength along the martian surface of about 200 km. All of the DSN Doppler tracking data over the entire mission life-time, including, if possible, data obtained during both the orbit insertion phase and the quarantine period, will be utilized in conjunction with the tracking data from earlier Viking and Mariner missions. These data will be reduced in orbital arc lengths of a few to a few tens of days duration, data continuity and integrity permitting.

When the orbit geometry is such that near vertical accelerations are observed, the tracking data will be converted into line-of-sight (LOS) acceleration maps along the orbit tracks. Opportunities for these observations occur near day TBD and day TBD of Figure 5-1 when Earth lies in the spacecraft orbit plane; the former provides south pole coverage and the latter gives north pole coverage. When combined with altimeter data, these profiles will allow for meaningful tests of various interior models and for estimates of model parameters.

Study of the density structure and stress state of the martian crust and upper mantle is to be conducted in conjunction with topographic data obtained from altimetry. Moreover, these data can be examined at the crossover points of the orbit to reveal the radial perturbation of the spacecraft during subsequent passages over the same location. On the basis of current knowledge of the martian gravitational field, the uncertainty of the radial position would amount to about 140 m; hence, crossover altimeter data with the expected accuracy of a few meters can provide significant improvements in determinations of both the orbit and the gravitational field.

It is uncertain at present whether the temporal variations in the gravitational field can be observed given the accuracy and quantity of tracking data described herein. A preliminary simulation indicates that the change in the dominant harmonic term, J2, is at the threshold of detection. The incorporation of additional altimeter data is expected to enhance the probability of success. Measurement of the time variation in the gravity field represents a major experimental and scientific challenge, but one of considerable significance to understanding the atmospheric seasonal cycle.

Ranging data will provide important constraints for use in the reduction of Doppler tracking data and will thereby improve the solution for the gravitational field. Of equal significance, the ranging data will be a valuable asset both for improving the ephemeris of Mars and for experimental tests of general relativity, possible subjects for investigation by a participating scientist.

D.6.3.3 Orbit Decay Measurements. In the process of determining the martian gravity field from the analysis of the orbital perturbations of the MGS spacecraft, accommodation will be made for any air drag that the spacecraft experiences. The frequency with which drag estimates will be obtained in the orbit determination process will depend on the magnitude of the drag effect, presently unknown by about two orders of magnitude. We expect to estimate drag at most about once per day, and at least about once per 10 days.

D.7 Thermal Emission Spectrometer (TES)

D.7.1 Investigation Description. TES will provide infrared spectrometric measurements of the surface and atmosphere of Mars in the 6.25 µm to 50 µm (1600 cm^{-1} to 200 cm^{-1}) region and radiometric measurements in both bolometric radiance (0.3 µm to 100 µm) and solar reflectance (0.3 ~m to 3.9 ~m) bands. Observations will be made from nadir to beyond the horizon to characterize the compositional and physical properties of surface materials and atmospheric aerosols and gases.

D.7.2 Experiment Objectives

The objectives of the Thermal Emission Spectrometer (TES) experiment are:

(1) to determine and map the composition of surface minerals, rocks, and ices;

(2) to study the composition, particle size, and spatial and temporal distribution of atmospheric dust;

(3) to locate water-ice and CO_2 condensate clouds and determine their temperature, height, and condensate abundance;

(4) to study the condensate properties, processes, and total energy balance of the polar cap deposits;

(5) to measure the thermophysical properties of the martian surface materials.

The TES experiment will determine the global mineralogic and petrologic character of the surface. Using infrared spectral observations, the primary rock-forming silicates, as well as silicate and nonsilicate weathering products, salts, and incorporated volatiles, can be distinguished. Individual mineral components can be identified and rock types distinguished, allowing both the mineralogy and petrology to be determined. Surface and atmospheric dust-volatile components can be discriminated using emission phase function and day-night observations. This ability is crucial to the interpretation of any remote sensing data. The global distribution of carbonates, nitrates, phosphates, and sulfates will be determined, both as components of the regolith and as localized concentrations, such as evaporite deposits. These minerals provide clues to the evolution of the atmosphere, its interaction with the surface, and the processes of salt deposition and migration associated with volatile cycles. The TES observations are complementary to VIMS, and Gamma Ray observations; there is no overlap in wavelength, the properties responsible for spectral features are intrinsically different, and the chemistry and mineralogy that can be determined are almost disjunct.

The composition and abundance of dust in the atmosphere and on the ground will be determined. Changes in dust opacity and distribution will be monitored during all phases of global and regional dust storms. Measurements at the limb and of single locations at variable emission angle allow unambiguous determination of atmospheric opacity and the spectral properties of suspended material. These results will provide constraints on the rates of dust erosion, transport, and deposition. Comparison of the composition of surface particulates and atmospheric dust will help to identify sources and sinks. Monitoring of the dust content during storm initiation and growth phases will help to determine the dynamics of storm generation and atmospheric circulation.

Water-ice and CO_2 condensates will also be identified in the atmosphere and on the surface from their spectral and temperature signature, providing clues to their diurnal and seasonal cycles as well. Cloud observations will be used to study the total water content within the atmosphere, and together with vertical temperature profiles, will provide strong constraints on the vertical distribution and saturation conditions of atmospheric volatiles. The composition, physical properties, and size of the seasonal and permanent polar caps will be monitored throughout the year, along with associated H_2O and CO_2 clouds and hazes. Unlike reflectance instruments, the TES can make observations in the diurnal and polar night, allowing observation of night and winter condensate formation in the atmosphere and on the surface. Thermal and albedo measurements of the perennial polar caps will allow a direct determination of the polar energy budget, with implications for the present and past climate.

D.7.3 Instrumentation. The science objectives of the TES experiment will be met using a Michelson interferometer with separate solar reflectance and bolometric radiance channels. The spectrometer covers the wavelength range from 6.25 to 50 µm (1600 to 200 cm^{-1}) with 10 cm^{-1} spectral resolution. The solar reflectance band extends from 0.3 to 3.9 µm; the broadband radiance channel extends from 0.3 to 100 µm. The instrument is 21.0 cm x 39.4 cm x 19.1 cm, with a mass of 11.1 kg and a power consumption of 13.7 W average by 2.5 W peak. It has six 8.3-mrad fields of view, each with 3-km resolution at the nadir, in each of the spectrometer, reflectance, and bolometric channels. Uncooled DTGS pyroelectric detectors provide a signal-to-noise ratio of over 1,000 for daytime spectral observations. The instrument performs a substantial amount of on-board processing, including the Fourier transform of the raw data, spectral editing, and spatial and temporal editing and averaging, in order to make maximum use of the downlink data rate. In addition, the data are internally buffered to provide flexibility between daytime, nighttime, and polar data. The instrument functions are outlined in Figure 2-19, and the detailed instrument performance description is given in Table D-7.

D.7.4 Measurement Approach The TES Investigation will make the following measurements:

D.7.4.1 Surface Composition. The TES experiment will provide a moderate resolution (3 km per element) map of surface thermal emission spectra for the entire planet. These data will be used to map surface compositional units and to study the mineralogy and petrology of the surface materials. For example, the composition of uplands and volcanic terrains provides information on the primary composition and degree of differentiation of the crust and upper mantle; the composition of weathering products and aeolian deposits will be used to study the source materials, mode of transport, and erosion processes; the composition of polar deposits provides clues to the source, origin, and bonding material of these deposits: the identification of carbonates and evaporites places constraints on the surface-atmosphere exchange through time.

A number of important geologic questions can be addressed by determining the composition and spatial distribution of primary and secondary (weathering) materials. One major question is the composition of the martian crust and what this composition implies about the state and degree of differentiation of the crust and upper mantle. Primary indicators of increasing magma differentiation are decreasing Mg/(Mg + Fe), decreasing Ca/Na, increasing SiO_2 content, and the abundance of K and Al_2O_3, which are reflected in mineral and rock compositions. The TES will measure of the variation in the mineralogy and petrology of the lavas as a function of their age, which will provide a direct measure of the evolution of martian magmas, both on a global basis and for individual eruptive centers.

Carbonates in the regolith may play an important role in the CO_2 exchange cycle, acting as a reservoir for long term exchange between the surface and atmosphere. Their presence also has important implications for the evolution of the martian atmosphere, placing constraints on the abundances and reaction chemistry of H_2 and CO_2. The TES spectral range covers a strong carbonate spectral feature that is separate and easily distinguishable from features in silicate and other mineral groups, allowing carbonates to be readily identified.

It is likely that aeolian processes have transported and locally concentrated fines of different composition and/or density. An important objective will be to isolate these and determine their composition. On a global scale, the composition and distribution of fines will provide a means for studying transport processes and determining the source regions of fine materials and the degree to which they have been redistributed. Salts and other binding agents within the upper regolith may be important in the surface evolution, and may provide important clues to volatile exchange between the surface and atmosphere. Carbonates, sulfates, nitrates, and phosphates all have distinctive absorption features that could be used to identify their presence in the regolith. Several large regions in the northern hemisphere have been proposed to be regions of active dust deposition, while other regions appear to be older surfaces which have formed surface or near-surface crusts.

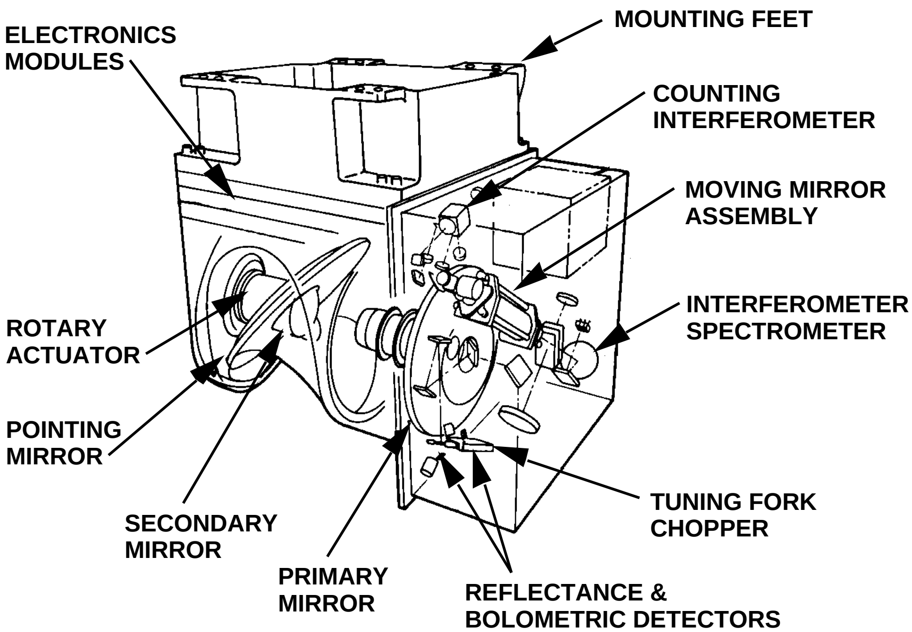


Figure D-15. TES Instrument

Measurement of the composition of these surface deposits will be used to distinguish between surfaces with and without bonding materials that would bear on the current models.

Both the major materials and possible bonding agents of the polar layered deposits are also of unknown composition. Identification of the composition and abundance of these materials may help to resolve the numerous models proposed for their formation, and may provide a link between the dust that is currently active and the material that comprises the individual layers.

D.7.4.2 Atmospheric Properties. The principal atmospheric properties to be addressed by this experiment are: (1) the composition, spatial and temporal distribution, and particle size of atmospheric dust, and (2) the distribution and condensate abundance of H_20 and CO_2 clouds. The TES also has significant potential for observations of the gaseous atmosphere. For example, apart from estimates of abundance of molecular species, essentially all of the atmospheric results of the Mariner 9 IRIS experiment could have been obtained with the spectral resolution of the TES.

Table D-7. Instrument Performance Description

Quantities to be measured:	Emitted radiance from 200 to 1600 cm^{-1} (6.25 to 50 µm) with 10 cm^{-1} (apodized) resolution Solar reflected radiance 0.3 to 3.9 µm Broadband radiance from 0.3 to 100 µm
Detectors:	DTGS Pyroelectric, all channels (uncooled)
Expected performance:	NEΔe @ 270 K & 10 µm = 0.04% in spectrometer NEΔT @ 270 K & 10 µm = 0.02K in spectrometer NEΔT @ 270 K = 0.003K in radiometer channel NEΔQ = 0.006% of solar flux in reflectance channel Dwell time - 1.8 s/IFOV

Optical/Mechanical Design:	15.25-cm Cassegrain telescope with pointing mirror to view nadir to beyond limb along track. Pointing mirror also provides image motion compensation, calibration, and stow functions. Separate 1.5 cm telescope for solar reflectance and thermal bolometric channels. Spectrometer is two-port Michelson Interferometer with corner-cube assembly mounted on a voice coil diaphragm with mechanical displacement of 0.5 mm. All aluminum construction.
Fields of View:	Six detectors (three across, two along track), each 8.3 mrad (3 km at nadir), for spectral, solar reflectance, and broadband radiance channels. All bands temporally and spatially coincident.
In-Flight Calibration:	Periodic views of space and internal blackbody.
Mounting Orientation:	Body fixed to spacecraft. Line of sight is stepped internally from nadir past limb to space, both fore and aft.
Thermal Requirements:	Operating range -10°C to +25°C. Nonoperating range -20°C to +40°C. No detector cooling required.
Data Rate:	Instantaneous internal rate is 1438 bps per IFOV. Data rate to PDS is adjustale; minimum, compressed rate is 416 bps. 0.5-Mbyte RAM internal data buffer.
On-Board Data Processing:	Digital filtering of oversampled interferogram. Fast Fourier Transform. Data processing and compression.
Mass:	14.56 kg
Size:	23 x 39.4 x 34 cm
Power:	15.55 W average, 18.20 W peak

To deconvolve thermal infrared data for determination of the abundances, vertical distributions and particle properties of volatiles, their condensates, and dust, the vertical temperature profile must be determined independently and concurrently. The 15-µm CO_2 band is ideal for this purpose. The unapodized resolution (5 cm-l) of the TES will permit retrieval of tropospheric temperatures up to the 0.3-mb level (~30 km). For a temperature error of 2 Ks the vertical resolution of the profiles will be slightly less than one scale height at the surface and two scale heights at 0.3 mb. TES observations of the limb will permit retrievals to ~70 km with a vertical resolution of one to two scale heights (14 km).

D.7.4.2.1 Dust. Studies of the composition, particle size, and seasonal variations of the dust will be made using thermal emission measurements. These measurements will provide constraints on (1) the growth and decay mechanisms of local and regional storms; (2) the spatial variation in dust opacity during clear periods, which may be related to the removal and redistribution of deposited dust; (3) the total dust load and resultant atmospheric hating; and (4) the amount of dust transported into the polar regions, with implications for polar energy balance.

Spectral measurement of the dust composition may serve to identify surface sources and sinks, and will provide information on the origin of materials injected into global dust storms. Important questions that remain are the rate of erosion by dust storms and whether the material is globally or locally derived. The spectral characteristics of dust during intense storms may provide evidence for large particles, possibly with different composition from the globally pervasive material studied previously.

D.7.4.2.2 Water Ice Clouds. Water is the most significant trace volatile in the martian atmosphere. Water-ice clouds will be mapped spatially and temporally using the characteristic spectral features at 229 and 800 cm^{-1}. From the strength of the spectral features and simultaneous knowledge of the vertical temperature profile, the height and water abundance of the clouds can be determined. If the clouds are optically thin, then the saturation level in the atmosphere can also be determined.

D.7.4.2.3 Gaseous Species. Water vapor abundance will also be determined directly by the TES, using bands near 1550 and 200-300 cm^{-1}. These will permit temporal and spatial variations to be mapped, particularly in limb observations, although at a lower abundance resolution than obtained by the Viking MAWD experiment. Direct measurement of ozone is also possible in limb observations, with a detection limit of 5 µm-atm.

D.7.4.2.4 Annual Surface Pressure Variation. The surface pressure will be determined, using the extreme wings of the 15-µm CO_2 band. The MGS ground track allows the maximum contrast between surface and atmospheric temperatures to be observed. This optimum viewing will permit significant improvement in the quoted 10% uncertainty obtained by IRIS. Thus, TES observations will be used to follow the seasonal cycle of surface pressure using repeated observations over the same regions. Of particular interest will be the erratic behavior of pressure previously observed by the Viking landers during global dust storm periods, and the measurement of the seasonal condensation and sublimation of CO_2 at the poles.

D.7.4.2.5 Atmospheric Dynamics. The zonal vertical wind shear (thermal wind) can be derived directly from the meridional temperature cross sections. Baroclinic eddies, which may play an important role in meridional transport, should be well mapped by TES. The M0 orbit will provide roughly three daylight and three night passes through each of these slowly moving (10-20 m/s), large (wave number 3-4) disturbances per day. Low-latitude, vertically propagating waves with vertical wavelengths of 10-30 km may be detectable at high altitudes in limb data.

D.7.4.3 Polar Cap Properties/Energy Balance. The nature of surface and suspended condensates can be determined in two ways using the TES observations: first, through direct identification of composition from spectral signature, and second through measurement of temperature. Material identification by temperature is useful when condensed water and CO_2 are present; although water is spectrally dominant, the presence of condensed CO_2 can be inferred from the seasonal and day-night variation of temperature. These surface temperatures are also important as they significantly affect the dynamics of the lower atmosphere. Surface and atmospheric components can be separated and distinguished, and some information on vertical distribution can be determined, using a series of observations at varying emission range. These observations provide a powerful technique for determining the composition and opacity of atmospheric aerosols. Direct observations of the total energy emitted and reflected from the polar caps, made at all seasons and at multiple emission angles, provide a means of determining surface properties of the ice, such as composition (to 10^{-5} mole fraction of H_2O), scattering properties (allowing estimates of particle size and roughness), and dust content, during all phases of cap formation and retreat. The total energy balance of the perennial cap determined by the TES will be used to study the seasonal effects of dust load, surface properties, and atmospheric heat transport on the rate of ice formation and sublimation in the current climate. These observations will be applied to climatic models to constrain the processes affecting the climate history of Mars.

D.7.4.4 Thermophysical Properties. In addition to emissivity variations, the emitted energy is also a function of the temperature and physical properties of the surface. Thus, such properties as particle size, rock abundance, subsurface layering, albedo, and packing, affect the spectral and diurnal character of the outgoing energy. IRTM observations, with limited spectral capability, proved very useful for determining the physical properties of the surface. The TES will map the thermophysical properties globally at a factor of 40 higher spatial resolution than is currently available.

The TES will also provide bolometric albedo observations of the surface, suspended dust, and polar materials. These measurements will be used to study surface albedo changes, the surface phase function (using variable emission angle measurements), atmospheric dust scattering properties, and polar cap dust contaminants.

D.8 Interdisciplinary Science (IDS)

D.8.1 Data and Archiving (Arvidson)

D.8.1.1 Investigation Description. The science objective is to utilize Mars Global Surveyor TES and imaging data in conjunction with digital mosaics of Viking Orbiter images to characterize and map the types and distribution of weathering products on the martian surface. First, Mars Global Surveyor data covering representative latitudes, altitudes, and geologic units sampled on a global basis will be used to characterize the types of weathering products exposed on the surface. This work should establish a global framework for understanding the types and distribution of weathered materials. Particular emphasis will then be given to selected equatorial and mid-latitude regions, including low-albedo areas where variations in Earth-based spectral reflectance values suggest variations in types of materials exposed. The regions chosen for detailed examination are given in Table 5-3, along with the rationale for selecting the particular locations. For each area a suite of digital maps depicting the occurrence and abundance of particular bedrock lithologies and alteration products will be prepared and delivered to Project Data Base. Detailed examination of these regions should establish, for example, whether or not weathering products exposed on the surface are locally derived and related to underlying bedrock. If such connections can be established, significant constraints on weathering mechanisms (i.e., mechanical breakdown, isochemical weathering, etc.) can then be drawn.

The overall goal is to use Mars Global Surveyor data to understand the mechanisms of weathering on Mars, temporal variations in mechanism efficacy, and implications with regard to cycling of carbon, water, sulfur, and other volatile species through the martian sedimentary system. Mars Global Surveyor will add demonstrably to meeting the goal, given that both mechanisms and timing of weathering of crustal materials are only poorly constrained with existing data. Consider that formation of palagonites during hydrothermal activity, the breakdown of rocks via salt weathering, and UV-photostimulated oxidation have all been proposed as important mechanisms, involving the production of up to kilometers in thickness of sedimentary debris.

D.8.1.2 Measurement Objectives. Mars Global Surveyor data from TES, MOC, and MOLA altimeter are crucial for meeting the science objectives discussed in the previous section. These data would be analyzed in concert with the global Viking digital image mosaics being generated by the USGS for the Project. Mars Global Surveyor data for the six areas to be examined in detail would also be examined in concert with sets of calibrated, multicolor Viking digital images to be generated at Washington University. The production of these image data sets is discussed in the Investigation Implementation Plan. As discussed, all available data would be used to generate a suite of digital maps depicting bedrock lithologies and alteration products exposed at the surface for the six study areas.

In all cases, Mars Global Surveyor data should be available in geophysical units in either standard, gridded formats, or with enough information to place a given derived parameter in a latitude-longitude framework. For TES, spectral emissivities for the 8-to-14 µm region are required to be able to characterize Restrahlen bands, such as those associated with fundamental stretching vibrations of Si-O. Since the Restrahlen wavelength is inversely proportional to the degree of sharing of oxygen atoms within the silicate lattice, these data provide direct information on silicate type. From MOLA, elevations are needed. Finally, both synoptic and high resolution MOC images would be needed. In particular, high resolution images over selected regions within the six study sites defined in Table One would be highly desirable.

TES reduced data would provide mineralogical constraints, while the Viking and MOC images would provide regional to local-scale information on morphology, color and relative albedo. When coregistered and examined collectively in map form, these data will significantly augment our understanding of the nature and distribution of martian weathering products.

D.8.2 Geosciences

D.8.2.1 Investigation Description. The general objective of this experiment is to exploit the complimentarity of the different MGS science instruments, both with each other and with those flown on previous missions, in order to better understand the geologic evolution of the planet. Three specific objectives are to:

(l) better understand the role of water in the evolution of the martian surface,

(2) characterize the volcanic history of the planet, and

(3) determine the nature and cause of the planet-wide dichotomy into uplands and plains.

Although only minute amounts of water are present in the martian atmosphere, water and water ice are believed to have played a major role in the evolution of the surface. Water may be present near the surface in a variety of forms. It may be unbound as ground ice, absorbed on minerals, or combined in a wide range of primary and secondary minerals. Knowledge of where on the planet, in what amounts, and in what form water is present is one of the main interests of this investigation, since such knowledge will lead to a greater understanding of the total inventory of water on the planet and the role that water has played in the various geologic processes that have resulted in the present configuration of the surface. The main sinks for unbound water are probably ground water, the polar layered terrains, ground-ice at latitudes greater than 30°, and ice-rich sediments, particularly in the low-lying area. Ground water, the largest potential sink, may be detectable if local seepages occur (oases). Water may also be absorbed on and bound within near-surface weathered debris, be common within products of volcano-ice interaction, and be contained within primary rock minerals. Salts such as carbonates, nitrates, and sulfates also have important implications for the water inventory.

A second major objective concerns the history and nature of volcanic activity on Mars. Although the morphology of martian volcanic features is now familiar, we have almost no information of the chemistry and mineralogy of the volcanic products. Analysis of weathered debris at the Viking landing sites suggests that the primary rocks are mostly Fe and Mg rich, and that Ca-Al-K-Na rich rocks are rare. This is also suggested by identification of pyroxenes and olivines in telescopic spectra. However, these tentative identifications are insufficient to identify specific rock types, to detect differences from place to place in primary rock mineralogy, or to make meaningful inferences about chemical and thermal conditions in the source regions. Volcanic features on Mars exhibit a wide range in morphology. While some of the differences may be due to eruption conditions, others are probably due to compositional differences. Any such compositional variations must reflect conditions at the sites of origin of the magma and any changes suffered by magma on its way to the surface. Volcanic products therefore provide a way of assessing chemical and thermal conditions at depths, and how they have changed with time.

The nature and cause of the planet-wide dichotomy into ancient cratered uplands and sparsely cratered lowland plains are major unsolved problems of martian geology. Lack of significant gravity anomalies correlated with the distribution the two crustal components suggests that the crust beneath the cratered uplands is less dense and compositionally different from the crust beneath the low-lying plains. The origin of the relatively light uplands crust is unknown, but it probably represents a light fractionation product of extensive melting during the very early history of the planet. The nature of the dichotomy thus provides information on very early events in the planet's history and additional clues of compositions in the interior.

D.8.2.2 Measurement Objectives. This investigation will utilize measurements from other instruments; it will not make measurements itself. However, to accomplish the above objectives certain general measurement requirements can be defined. The first is to acquire complementary TES and altimetry data of the entire surface of the planet at the maximum spectral and spatial resolution consistent with downlink constraints. The second is to sample all identifiable geologic units at the maximum spectral resolution possible. Many units have already been identified from Viking data and additional units will emerge as the Mars Global Surveyor mission progresses. The main hindrances to acquisition of these data will be masking of the surface by dust, the need to keep command sequences relatively simple, and limitations on data acquisition imposed by downlink constraints. Accomplishment of the objective of sampling all geologic units by MOC and by other instruments at maximum spectral resolution implies some targeting. However, TES can trade spectral and spatial resolution, and MOC samples only minute areas. Limited targeting can be effected by timing and mode changes, but in order to achieve this general requirement we must know where bedrock is best exposed. The observational strategy early in the mission should, thus, emphasize identifying where bedrock is best accessible to observation. The specifics the strategy remain to be determined.

A major hindrance to accomplishment of the objectives outlined above will be the presence of dust. It is anticipated that bedrock will show through the near surface dust on only a small fraction of the surface. Broad areas may be swept free, but large dust-free areas are very unlikely. More likely all observations will include some dust component. We know that some parts of the planet, particularly in low southern latitudes, may be relatively dust free, and elsewhere there may be local windows, such as dark crater streak, through which the bedrock can be observed. However, these areas not now sufficiently well defined that an observing strategy can be confidently formulated. Toward the start of the mission therefore, we need to acquire the data appropriate for compiling a dust distribution map. Because the distribution of the dust may differ slightly before and after the dust storm period, one dust map may not be sufficient. A proposed intent of this investigation is, therefore, to produce dust maps of the planet while the mission is in progress. These, when combined with existing geologic maps, will provide a guide to subsequent measurements to ensure that all major geologic units exposed at the surface are sampled at maximum spectral resolution, and with minimum interference from dust. This goal will help satisfy all scientific objectives that rely on information from bedrock.

One goal of this investigation is to identify the location, distribution, and water content of these various sinks, insofar as it is possible from observations of the surface. A possible product of the investigation would be a volatile distribution map which shows the distribution of different sinks for water, together with their water content, the distribution of volatile-containing species, such as carbonates and nitrates, and the location of possible seepage sites. However, because of the sensitivity of the MGS instruments to only the very near surface materials, because of the vagaries of the local dust cover, and because of the effects of climatic factors which affect the stability of unbound water, such a map is unlikely to directly yield a global water inventory. This must be assessed by extrapolating downward from the surface on the basis of what is known of the geology, and any such assessment will be very model dependent. Possible additional products of the investigation will be an estimate of the global inventory of water and other volatiles, an assessment of where these volatiles are now and how they have been redistributed with time, and a reevaluation of the role of water in various geologic processes. Products expected from the volcanic study and the study of the planet-wide dichotomy range from paleovolcanic maps which show the distribution and types of volcanic rocks and how they have changed with time, to theoretical papers on the petrologic implications of the surface measurements, and assessments of the density, composition and thickness of the crust under the highlands and how it contrasts with that in the opposing hemisphere.

D.8.3 Polar Processes (Ingersoll)

D.8.3.1 Investigation Description. The polar regions contain the volatile reservoirs and are thus the key to martian climate. The basis objective is to define the atmospheric circulation at all seasons in enough detail to specify the poleward transports of CO_2, water, dust, and energy, as well as the radiative and surface fluxes of these same quantities, particularly in the polar regions. By taking the broadest possible objectives for climatology it will ensure that no measurements fall between the cracks that separate one instrument from another. Thus the basic objective is to see that MGS gathers the best climatology data set that it possibly can.

D.8.3.2 Measurement Objectives. The specific contribution of this investigation to the MGS mission will be to oversee the production of daily synoptic weather maps, to estimate the vertical fluxes in the atmospheric boundary layer, and to integrate all observations pertaining to the mass and energy budget of the polar regions.

(1) Synoptic Maps

The orbit of the MGS spacecraft is ideal not only for geologic mapping, but also for intensive studies of the poles and for synoptic studies of the atmosphere. A synoptic map is defined to cover a large area, possibly the globe, with observations taken over a short time interval, basically a snapshot. In one day the atmosphere can be sampled at 12 equally spaced longitudes on the day side (24 if nightside passes are included). This sampling makes it possible to separate the longitudinal mean distributions (of temperature, pressure, wind, water vapor, dust, etc.) from the eddy distributions up to zonal wave number 6. Atmospheric mapping instrument (TES, MOC) will produce synoptic maps of everything they can measure. Members of the various instrument teams will produce synoptic maps of wind and pressure -- two quantities where an interdisciplinary approach is called for. To the extent possible these maps will resemble ordinary weather maps of surface pressure and surface wind as well as altitudes and winds on constant pressure surfaces in the atmosphere. The data rate should allow daily global mapping for the entire mission at low resolution. More intensive mapping, which uses most of the science data rate for a 30-day period, should be possible at several representative times during the year.

The spacing of points on a low-resolution map might be 15 or 30 degrees in longitude and 10 or 15 degrees in latitude. With several altitudes and data quality indicators, each map might contain a few thousand floating-point numbers, certainly a manageable data set. We will work with other investigators to produce complete weather maps for the 30-day "atmospheres intensive" periods. We will rely on instrument teams to reduce their data from raw radiances to physical parameters. This investigation will combine data from different instruments to produce the global maps.

While not as dense or as high in quality as terrestrial weather maps, the MGS synoptic maps should allow estimates of horizontal transports. If each instrument uses the same mapping format (the same global grid based on the spacecraft ground track), calculation of variances and covariance should be straightforward. Transports of CO_2, water, dust, heat, and momentum will emerge from the covariances. The volume of data is small and presents no problems. Difficulties will arise from nonuniform data quality and marginal sampling in longitude, particularly in view of the large topographic variations with respect to longitude. These problems can be handled by good algorithms with realistic estimates or error.

The major effect before launch will be to develop algorithms for data assimilation. This is a standard problem in terrestrial weather forecasting. The data are collected continuously in time at different places, yet one wants an instantaneous (synoptic) map of the entire globe once each day. Furthermore, the data are of uneven quality -- temperatures will be measured more successfully than winds, for example. The solution is to use a dynamical numerical model to interpolate between observations at different times and to connect those quantities that are poorly measured to those that are well measured, using the equations of motion as a constraint. The results are relatively insensitive to details of the numerical model if the interpolation is over a relatively short time, i.e., 1 day. Various numerical models, including the Mars General Circulation Model (GCM), will be evaluated for this data assimilation activity.

(2) Vertical Transports

Exchange of heat, dust, momentum, and water between atmosphere and surface can be estimated from boundary layer theory provided the surface pressure, surface temperature, wind speed, atmospheric humidity, atmospheric temperature, and dust content are known. As stated above, some of these quantities individually require more than one instrument. Combining the quantities to produce a vertical flux requires several measurements and is always interdisciplinary.

The major effort before launch will be to develop algorithms to estimate vertical transports from the theory of the planetary boundary layer (PBL). Modeling the PBL is a standard problem in terrestrial weather forecasting, but the parameter ranges (e.g., surface pressure) are different on Earth and Mars. Also the synoptic maps on which the PBL estimates depend are more uncertain than on earth. Realistic estimates of error are an important part of this activity.

(3) Polar Mass Budgets and Energy Budgets

TES can measure the energy exchange at the top of the atmosphere by infrared and visible radiation. This fundamental measurement benefits from using the capabilities of both instruments. In the infrared, TES samples different parts of the spectrum with some overlap. The scan patterns of the two instruments help to cover the range of directions into which sunlight may be scattered. These two scan patterns complement each other in defining the radiative energy budget of the polar regions. Since much of the CO_2 and water are locked up there, the poles are critical for understanding martian climatology.

Several other archivable products will be produced from my interdisciplinary studies of the polar regions. By combining radio occultation studies of surface pressure at high latitudes (the ingress points) with the proposed gravitational measurements, it should be possible to plot pressure versus time at a reference equipotential altitude, thereby repeating the measurement of seasonal pressure cycles that was originally made at the Viking Lander sites. With radiative fluxes and heating rates determined by TES, all the terms in the energy balance of the polar regions will be known. The energy inputs will then be converted to sublimation rates and compared with seasonal pressure changes.

D.8.4 Surface-Atmosphere Interactions (Jakosky)

D.8.4.1 Investigation Description. The interdisciplinary science investigation discussed here is to determine the nature of the interaction between the surface and the atmosphere of Mars using data from a variety of relevant instruments on the Mars Global Surveyor (MGS) spacecraft. This analysis is distinct both from a pure surface or a pure atmospheric approach, and is appropriate due to the interactive nature of the processes involved in the formation and evolution of the martian surface and atmosphere. Most of the processes involved in the evolution of the surface and atmosphere. Most of the processes involved in the evolution of the surface or atmosphere, in fact, involve an interaction between the two. This is the case for simple weathering of the surface, involving chemical interaction with the atmosphere, exchange of volatiles between the atmosphere and surface (as in frost-weathering), or eolian transport of surface materials. It is also the case for the evolution of the atmosphere and climate, with changes in the solar flux or Mars' orbital elements driving exchange of volatiles (water and carbon dioxide, predominantly) between the atmosphere and nongaseous reservoirs in the polar regions or in the near-surface regolith. In fact, the main observable properties of the surface and atmosphere my result from interactions between the two.

The specific scientific questions to be addressed by this investigation are the following:

(1) How much of the observed seasonal atmospheric water vapor behavior is explained by exchange of water with the seasonal and residual polar caps?

(2) How much of the observed seasonal atmospheric water vapor behavior is explained by exchange of water with the regolith?

(3) What is the nature of the seasonal interaction between water and fine materials on the surface and in the atmosphere?

(4) Is water involved in the short- and long-term evolution of the near-surface layer?

(5) How does the near-surface layer evolve with time?

(6) What is the nature of the seasonal interaction between the carbon dioxide polar caps and dust?

(7) What is the nature of the seasonal interaction between carbon dioxide and water?

Of necessity, these questions overlap to some degree and are not exhaustive of the possible surface-atmosphere interactions. They do provide a framework, however, for understanding the evolution of the Mars surface and atmosphere. They also represent a series of questions that can be addressed by both observational and theoretical analyses, based on measurements to be provided by instruments which are part of the MGS payload.

Figures D-16 and D-17 show in schematic form the nature of the Mars climate system and of that part of it which related to surface-atmosphere interactions Much of the MGS mission has as its goal the quantitative understanding of the arrows and ovals in Figure D-16, thereby providing an understanding of the current nature of the Mars atmosphere and the mechanisms by which the current atmosphere and near-surface layer are evolving. This investigation has as its goal the understanding of Figure D-17, the processes involved in the interactions between the surface and the atmosphere.

The approach for this investigation is twofold. First, direct comparisons of individual data sets will provide constraints on specific processes involving the surface and atmosphere. These data comparisons involve atmospheric dust and volatiles and surface physical properties. Second, there will be specific analyses of several data sets in order to derive specific surface and atmospheric properties. For instance, use will be made of TES data to derive surface dielectric properties, and of TES data to understand the near-surface atmospheric boundary layer.

Anticipated results of this investigation include the following: global high-resolution maps of surface dielectric constraint and its relationship to other surface properties; global synoptic analyses of near-surface atmospheric water vapor; synoptic analysis of observations pertinent to the summer residual north polar cap and to the sublimation of water vapor from its surface; synoptic analyses pertinent to the sublimation of water from the edge of the retreating seasonal polar caps ;and to the entrainment of water within the cap itself; synoptic analyses pertinent to the seasonal exchange of water between the atmosphere and regolith, including the vertical distribution of atmospheric water vapor, the physical properties of the near-surface regolith, and the presence or absence of surface or subsurface ice; synoptic analysis of the possible simultaneous transport of dust and water into the winter north polar region during the global dust storms; maps of the water/dust ratio of the residual polar caps, and of its relationship to other surface physical properties; global maps of near-surface hydrogen and its relationship to her physical properties; and synoptic analyses of the saturation state of atmospheric water.

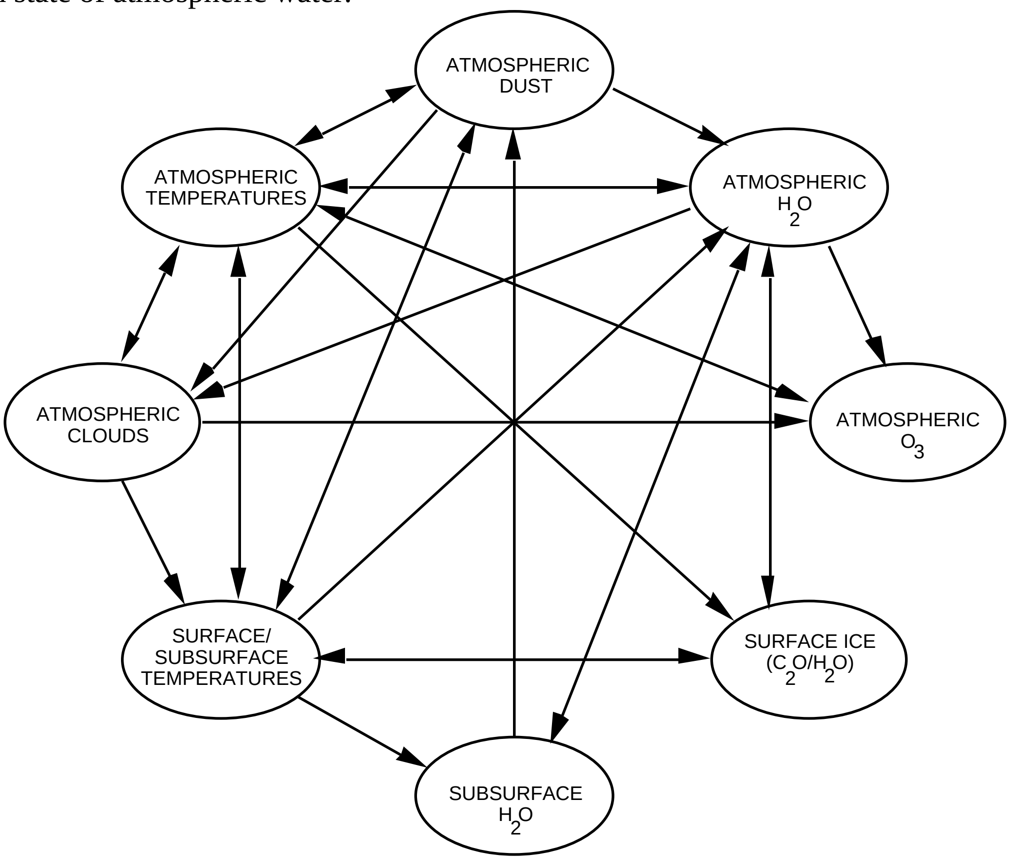


Figure D-16. The Mars climate system

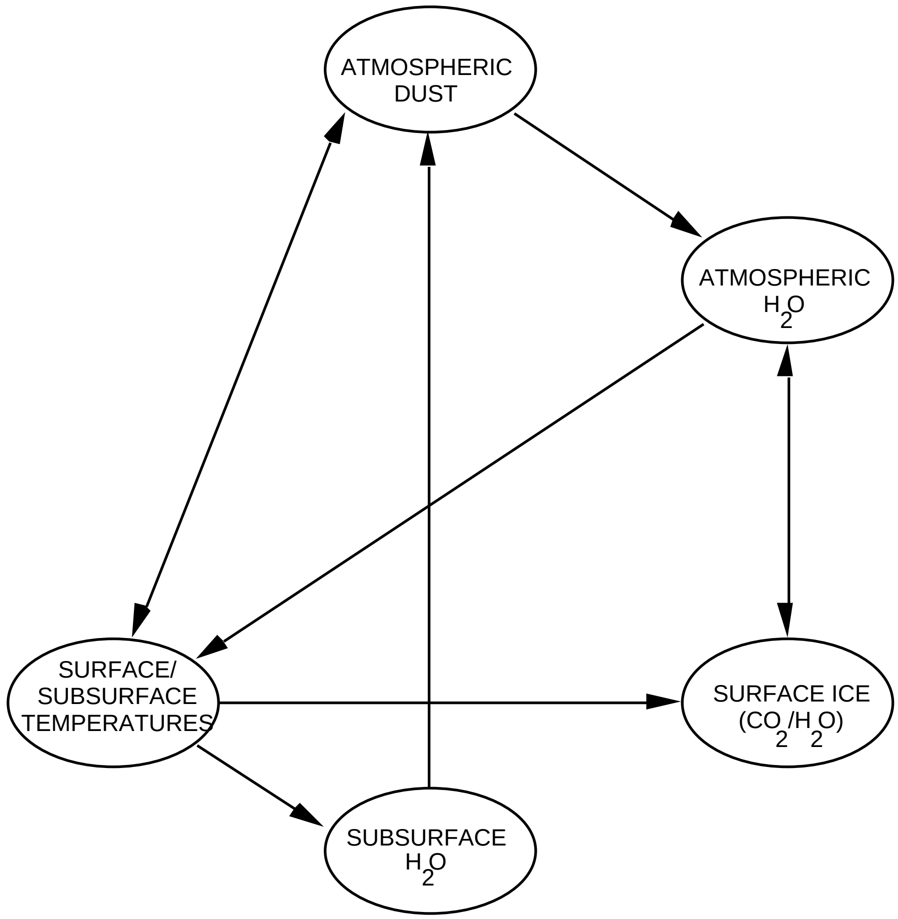


Figure D-17. The part of the Mars climate system which relates to surface-atmosphere interactions

In Figures D-16 and D-17, the ovals generally represent measurable or physical properties of the surface or atmosphere, while the arrows represent processes (not specifically enumerated here) by which one property (at the tail of the arrow) can influence another (at the head).

D.8.5 Climatology (Haberle)

D.8.5.1 Investigation Description. The objectives of this investigation are to:

(1) Assess the influence of suspended dust particles on the atmospheric general circulation of Mars. This analysis will include quantitative assessment of the enhancement of suppression of various components of the circulation by different amounts of dust. The components of interest include the Hadley circulation, baroclinic eddies, barotropic eddies, topographically induced eddies, and, if possible, certain tidal modes.

(2) Determine the physical factors that control the life cycle of global dust storms. This objective includes an evaluation of the factor that allow a global dust storm to grow to global proportions, the feedback relationships between dust heating and dynamics that allow it to grow and the ones that cause the storm to quickly enter into a decay phase once it has grown to global proportions. Also of interest is the relationship between baroclinically induced dust storms at the mid-latitudes of the northern hemisphere and the occurrence of global dust storms, which begin at southern mid-latitudes.

(3) Evaluate the role of dynamics in the seasonal cycle of water. In particular, this study includes a determination of the transport of water vapor and condensed water clouds from such source regions as the summer northern cap and low latitude regolith to their surface sinks.

(4) Investigate the transport of dust and into the polar regions and their effects on the stability of carbon dioxide ice deposits. This objective includes a determination of the amount of transport of suspended dust and atmospheric water into the polar regions by various components of the atmospheric circulation and the influence of these material on the stability of the ice deposits.

(5) Estimate the modulation of the atmospheric circulation and the seasonal cycles of dust and volatiles induced by astronomical variations of orbital eccentricity and axial obliquity and precession. This objective is directed at understanding some of the factors that led to the formation and maintenance of the polar layered terrain.

(6) Evaluate the constraints placed on the possibility of an early dense carbon dioxide atmosphere by surface mineralogy and investigate the impact of a denser atmosphere on surface processes.

D.8.5.2 Measurement Approach. A primary tool for carrying out the theoretical investigations outlined in section A is the Mars GCM. This mode has been developed over the last ten years. It was initially used to predict wind conditions at possible landing sites for the Viking landers. It was later used to assess the influence of the large horizontal scale, large amplitude topography of the surface on the atmospheric circulation for dust-free conditions. Most recently, allowance for the radiative impact of suspended dust particles has been incorporated into the model. Production runs of the revised model will be done to study the influence of varying levels of dust on the circulation. These runs will be done for temporally and spatially constant dust loading in a given run. Over the next several years, contemplated improvements to the model include tracer studies in which the feedback relationships between dust heating and its spreading by winds are explored and the inclusion of relevant physical processes to study the seasonal water cycle.

The Mars GCM is a fully three dimensional model of the atmospheric circulation based on the primitive equations of meteorology. The equations are in a sigma coordinate system so that topographical variations can easily be included. Off-line, accurate radiative transfer calculations are made to specify the radiative heating rates by such optically active species as dust and carbon dioxide gas. Graphical packages have been developed and will continue to be developed so that the results of simulations can readily be diagnosed. Results from a given run are stored on history tapes that provide values of all key variables at every grid point on time centers of every one and one half hours.

The following products will be available during the experiment implementation phase:

(1) History tapes containing values of all key variables computed by the GCM on time centers of every 1.5 hours of simulated time at every grid point. Tapes will involve simulations for different levels of dust loading, dust spreading, and water cycle simulations. Copies will be available for simulating instrument performance.

(2) Graphical outputs of the above simulations. Graphs include time averaged and zonally averaged winds and temperatures, heat and momentum transports by various wind components, time averaged surface stress maps, and instantaneous maps of wind vectors and geopotential contours.

During the mission operations phase, general circulation model (GCM) simulations will be made incorporating recent Mars Global Surveyor data to be used for planning purposes. Graphical results as described above will be available from these simulations.

D.9 Campaigns

In addition to the Gravity Campaigns, periods of continuous tracking and real-time data return (up to seven consecutive days) will be required for the following observations. No special spacecraft attitude or maneuvers are required.

Diametric Earth Occultations

During periods when the spacecraft ground track corresponds with that of the radio signal to earth and Radio Science (RS) and the Thermal Emission Spectrometer (TES) can view the Mars atmosphere through the same air mass, DSN coverage is required for 12 hours before and after the time of the diametric earth occultation. These observations provide validation information for the retrieval algorithms used for deriving atmospheric profiles by RS and TES.

Geodesy

During four 7 day periods (only three such periods are needed if the 80 Ksps real-time rate is used) when the Mars atmosphere is expected to be reasonably clear (such a period is expected to occur in early 1999) continuous tracking and real-time data return is required. For each 7 day period real-time coverage is needed for 8 out of every 12 orbits. The orbit sets to be used and the time between 7 day periods will be adjusted from one 7 day period to the next to provide full planet coverage. If possible the four periods should be arranged so that the polar regions are illuminated in at least one of the four periods.

Global Color Imaging

At about 6 month intervals the coverage is required to provide four consecutive passes to allow moderate resolution (1 to 1.7 km/pixel) two color images of the illuminated portion of Mars to be obtained.

Atmosphere

For the purpose of obtaining concentrated observations of the atmosphere during periods of special interest (e.g. initiation of dust storm and winter storms, carbon dioxide ice clouds in the North and South polar region, mid-spring water release, closing of the dust storm period, and water transport across the equatorial zone) up to 4 seven day periods of continuos DSN coverage are required. Observations of the type of interest here can be made during the Gravity and Geodesy Campaigns except in a few cases where additional 7 day periods will be required

E. MARS RELAY REQUIREMENTS

E.1 INTRODUCTION

The Mars Relay (MR) is a French-provided radio system carried on the Mars Global Surveyor spacecraft to relay measurements to Earth from instrumented surface or near surface stations to be released by the Russian Mars '96 and future missions. Orbiting Russian spacecraft will provide for basic data return from the surface stations. However, the MR has the advantage of being on a spacecraft in a relatively low circular orbit, permitting excellent view times and consequently a significant data return. The term "surface station" refers to the planned release of two small surface stations and two penetrators around the time of the Mars '96 spacecraft orbit insertion around September 1997. A brief description of the Mars '96 mission is given in Section E.8

The MR antenna is mounted on the spacecraft nadir panel to produce a signal (beacon) indicating its proximity to the surface stations and trigger an uplink response of telemetry. The MR utilizes the large memory of the Mars Orbiter Camera (MOC) to buffer the surface station data prior to transmittal to Earth. Although the MR also was designed to support balloon gondola telemetry, some of these functions will not be used during the Mars '96 surface station operations (e.g., two-channel 128-kb/s telemetry receive capability). At this time there exists a possibility that the MR could provide support to a Russian Mars '98 mission which would release at least one balloon into the atmosphere of Mars late in 1999. This activity is described briefly in Section E.9

The general architecture of the MR is shown in Figure E-1. The MR is composed a UHF antenna that is used both to receive the telemetry from surface stations and to transmit a modulated beacon, and an electronics module consisting of the following:

A UHF diplexer unit.

A UHF coherent receiver that includes carrier demodulation and bit detection in soft decision for the two carrier frequencies and bit rates of the surface stations. The receiver will compensate for the Doppler shift due to the satellite velocity and will achieve carrier tracking during the pass of the satellite. The receiver will deliver a locally synchronized signal to the Doppler unit.

A commandable Viterbi decoder adapted to the 7-1/2 convolutional code utilized in the balloon gondolas or small stations

A 2.56-MHz TCXO (clock)

An interface adapter with MOC that transforms the output signals (data and clock) in the proper interface signal required by the MOC specifications

A Doppler module that performs Doppler measurements of the station telemetry carrier. This unit performs digitization of the Doppler measurements, which are correlated with the satellite local time. This unit is also used to perform conditioning and formatting functions on the corresponding data.

A mass memory unit to store the data from the Doppler module and the housekeeping telemetry unit. This unit permits temporary storage of these data while waiting for the end of the station messages.

A beacon and subcarrier generator

A beacon transmitter and frequency modulator. The modulated beacon constitutes the interrogation signal for the stations.

A power supply unit to adapt the 28-V power bus line to the equipment of MR. This unit provides the needed power lines and voltages to the MR equipment. A 10-V line feeds the interface circuits.

A command interface unit to adapt the command lines from the Mars Global Surveyor spacecraft and to provide up to 16 on/off commands for use by the MR payload.

A housekeeping telemetry (HKTM) conditioner. This equipment is used to perform MR telemetry sensor sampling, conditioning, and digitizing, and to transmit the corresponding data to the MOC by the same interface as for the scientific telemetry and Doppler and spacecraft time data. The HKTM unit will be connected to the Doppler unit or the memory.

Two thermistors for thermal control of the MR by the Mars Global Surveyor spacecraft.

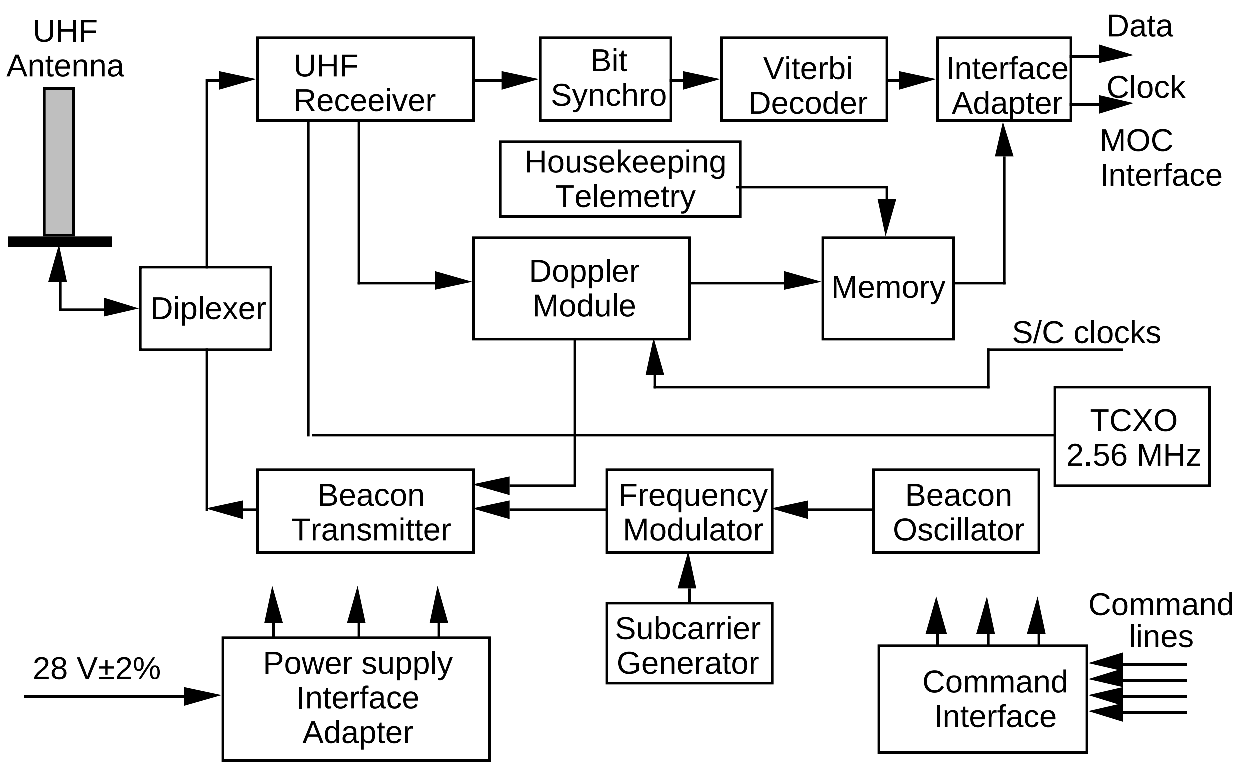


Figure E-1. General Architecture of the Mars Relay (MR)

E.2 REQUIREMENTS SUMMARY BY PROJECT ELEMENT

E.2.1 Spacecraft

(1) MR requires a spacecraft attitude such that data can be acquired from surface stations and passed to the MOC.

(2) The antenna must be located with clear field of view (FOV) and no shadow mask.

(3) There shall be 16 available commands via four discrete lines from spacecraft.

(4) It shall be possible to collect surface station data during both the nighttime and daytime portions of the spacecraft orbit.

E.2.2 Mission Operations

(1) Orbital trim maneuvers should be avoided during the actual MR acquisition of surface data to optimize station position knowledge.

(2) The MR requires spacecraft event timing knowledge to ±20 ms relative to Universal Time (UTC). It is a goal to have DSN tracking during surface station uplink transmission to the MR.

(3) The MR shall be exercised during the early payload checkout and prior to Relay operations.

(4) The link between the Jet Propulsion Laboratory (JPL) and MOC facilities shall support recovery of MR data files within 1 hour after their arrival at the Mars Global Surveyor Project Data Base (MGS PDB) during the nominal operation periods.

(5) MR operations support shall commence about 10 September 1997 and extend through the end of the mission Relay phase to cover the surface station activities.

(6) The MR data shall be available for retrieval by the monitoring and analysis team at the MOC facility each day of operations within 24 hours after Earth receipt.

(7) The quality, quantity, and continuity (QQC) of the data shall be >95% of ground-received telemetry, with a BER of $\leq 10^{-5}$ and a maximum gap duration of 10 seconds.

(8) The workstation at the MOC facility (SOPC) shall have the following capabilities: prediction of MGS spacecraft path, access to the PDB, command generation, communication with investigators, and graphic image display. In addition, software provided by the MOC/MR team shall be supported by the SOPC/MOC computers to predict the Mars Global Surveyor trajectory and provide reconstruction of station locations and telemetry depacketization and decompression of MR data.

(9) The SPICE kernels shall be available to CNES and the MR team during surface station operations.

(10) The MR beacon shall be operational such that data can be returned from all stations.

E.2.3 Payload

(1) The nominal data rate between MR and MOC shall be 16 kb/s (Doppler, housekeeping) or 8 kb/s.

(2) MOC shall allocate sufficient memory and data transmission capacity to the daily return of relay data from MR during surface station operations.

(3) MOC shall packetize MR data and make them available for spacecraft transmission consistent with the daily operations requirements.

(4) MOC shall support the MR in-flight test activities described above.

(5) The capability to decompress both MOC and MR telemetry and deconvolve station instrument data shall be available at the MOC facility.

(6) Access to the PDB for MR users shall be available at the MOC facility.

(7) A link between the MOC facility and the CNES facility shall support two-way electronic transmission of files to send all the MR data to CNES.

(8) Reduced records (200 Mb/station) shall be archived on the PDB as compressed MOC data, with access consistent with Project policy.

E.3 TRAJECTORY REQUIREMENTS

E.3.1 Mapping Orbit Parameters

The orbit of Mars Global Surveyor will be approximately circular and thereby should optimize viewing time (to support both daytime and nighttime passes). The corresponding Mars '96 orbit permits viewing of the surface stations at a different time from the MR viewing period, in order to provide (1) a range of atmospheric conditions, (2) a suitable period for new data to accumulate, and (3) a possibility of detecting changes in the nominal station operations.

E.3.2 Navigation

It is a goal to locate the position of the small stations on the surface of Mars to within 1 km to expedite the correlation of Viking images with those taken by the panoramic cameras.

E.3.2.1 Doppler Positioning. The MR includes a capability for Doppler ranging. The precision of location of a surface station is the quadratic sum of two terms. The first term is proportional to the precision of measurement aboard the MR. Assuming a path view of 10 minutes, with three measurements every 16 seconds at a precision of 4 Hz, the expected accuracy, which is also dependent on the frequency stability of the station transmitter, is 1.5 km.

The second term is dependent on the precision of the spacecraft location. The surface station locations will be determined initially using SPICE kernel predicts. After 14 days of tracking, the final SPICE data giving the spacecraft state vector and covariant matrix, together with DSN tracking data acquired during passes over the station, will be used to provide the ultimate surface station location.

E.3.2.2 Maneuvers. Orbital trim maneuvers should be avoided during the actual MR acquisition of surface data, to optimize their position knowledge. A maneuver should occur at least two days prior to the data relay (goal).

E.3.3 Cruise/Transition Orbit

The MR/MOC interface and MR shall be exercised during inner cruise, in order to check out their functions.

E.4 SPACECRAFT AND DSN SUPPORT

E.4.1 Instrument Location, Alignment, and Field of View

E.4.1.1 Location. The antenna shall be located with a clear FOV. There shall be no shadow mask in the FOV. The antenna shall be omnidirectional and have an axial ratio of <4 dB received and <6 dB transmitted.

E.4.1.2 FOV. The FOV shall be conical with an angular width of 63° from nadir half angle.

E.4.1.3 System Parameters. The MR system parameters are given in Table E-1.

E.4.2 Environmental Requirements

Environmental requirements (refer to ICD) include:

temperature:	electronics	–10° to +40° C (operating)
		–30° to +40° C (nonoperating)
	antenna	–100° to +100° C
electromagnetic fields:		See ICD
size:	electronics	25 x 25 x 20 cm
	antenna	71.8 x 10 (dia.) cm
power:		9.6 W
mass:	electronics	5.83 kg
	antenna	2.05 kg

Table E-1. MR System Parameters

Parameter	Balloon 1*	Balloon 2*	Surface Stations
Receive frequency (MHz)	401.5275	405.625	401.5275
Modulation[1]	F_1/F_2	F_3/F_4	F_1/F_2
Coded bit rate (b/s)	128,038	129,344	8003
Occupied bandwidth (kHz)	1024.296	1034.752	64,018.5
Transmit frequency (MHz)	437.100	437.100	437.100
Required signal strength (dBm)[2]	–116	–116	–128
RF output, minimum (dBm)[3]	30	30	30
Antenna:			
Minimum gain at 64° (dBi)[4]	3	3	3
Polarization	RHCP	RHCP	RHCP
Axial ratio (dB)	4 max	6 max	4 max

[1] F_1 = 1484.06 ±0.002 Hz
F_2 = 1376.34 ±0.002 Hz
F_3 = 1137.78 ±0.002 Hz
F_4 = 1028.11 ±0.002 Hz

[2] Signal strength is measured at the output of the antenna.

[3] RF output is measured at the input to the antenna.

[4] Referenced to the MR receiver input for a linearly polarized uplink signal.

*Not used during Mars '96 mission support.

E.4.3 Pointing and Timing Requirements

MR requires a spacecraft attitude such that data can be acquired and passed to the MOC twice per day. Radio links are possible whenever the sub-spacecraft longitude is within 17.7° of the station longitude, assuming a minimum elevation of 10° and a spacecraft altitude of 380 km.

The MR-station bit rate is 8 kb/s, and the maximum view period should be approximately 8 minutes.

The accuracy for the clock signal supplied to the MOC for data tagging affects the accuracy of the Doppler measurements.

The Doppler measurement principle is as follows:

The Mars Global Surveyor spacecraft transmits to the MR the 1-Hz signal and the corresponding onboard time data. The MR starts the Doppler measurement on a given 1-Hz pulse. The MR determines the Δt between the end of the Doppler measurement phase and the next 1-Hz pulse. The result corresponds to the datation of the Doppler measurement.

The Doppler unit will perform the receive frequency measurement and indicate the starting time of the measurement. The frequency measurement will use an internal TCXO operating at a frequency of 2.56 MHz ($\pm 5 \times 10^{-9}$/min).

The recording of starting time measurement will use the Mars Global Surveyor spacecraft local time signal. The time will be delivered to the MR with the following four signals:

(1) Time Code Sync (1-Hz signal)

This signal is provided by the spacecraft every second and indicates when the Time Code Data signal was latched into the buffer. This signal will also serve as a data-ready indicator to the MR.

(2) Time Code Data Enable

This signal will be initiated by the MR at the start of the first data bit of the time word and will terminate at the completion of the 39th bit of the time word. During the time that the enable signal is present, the MR will supply 40 clock pulses at a rate of 16 kHz. The time code data will be transferred to the MR, MSB first, on the leading edge of the clock pulse. The precision of the time code is 1/256 second.

(3) 16-kHz Clock

The data transfer will operate with reference to a 16-kHz clock provided from the MR using a 2.56-MHz TCXO oscillator signal.

(4) Time Code Data

Time code data, consisting of 40 unambiguous significant bits (LSB resolution is 4 ms) will be delivered by the spacecraft.

The MR requirement for accuracy in timing spacecraft events is ±20 ms (referred to UTC).

Momentum wheel dumps should occur outside the data acquisition periods if possible. If not, the spacecraft team should inform the MOC/MR team of those events.

E.4.4 Calibration Targets and Sources

The MR shall be exercised as follows:

(1) Check out in early cruise of MR, MOC, and PDS in conjunction with MOC checkouts.

(2) Check out prior to Relay operations similar to (1).

E.4.5 Data Transmission Requirements

E.4.5.1 Station to Spacecraft. The data rate from the surface stations to the MR is 8 kb/s, and during a typical pass 0.5 to 4 Mb will be uplinked to the MR. The link margin shall be 4 dB over a ≤10-minute relay interval. Up to two passes per day per station shall be supported.

The Station Telemetry format follows the time diagram shown in Figure E-2. The characteristics of the message format will be the same for any station. The message duration is time limited, and the transmission of the message by the stations is commanded by the request beacon. The format is divided into three parts:

(1) A carrier acquisition phase providing time to insure the capture of the carrier by the receiver phase-locked loop; the duration of this preamble is 1 second.

(2) A "Viterbi PN sequence" used to synchronize the Viterbi decoder. This sequence is consists of k+1 identical 511-bit patterns (i.e., (k+1) times 1022 coded symbols).

(3) The telemetry bit sequence, whose length depends on the signal quality but is limited to the 10-minute period defined above.

The loss of the message will be detected by the receiver using the lock signal of the carrier tracking loop.

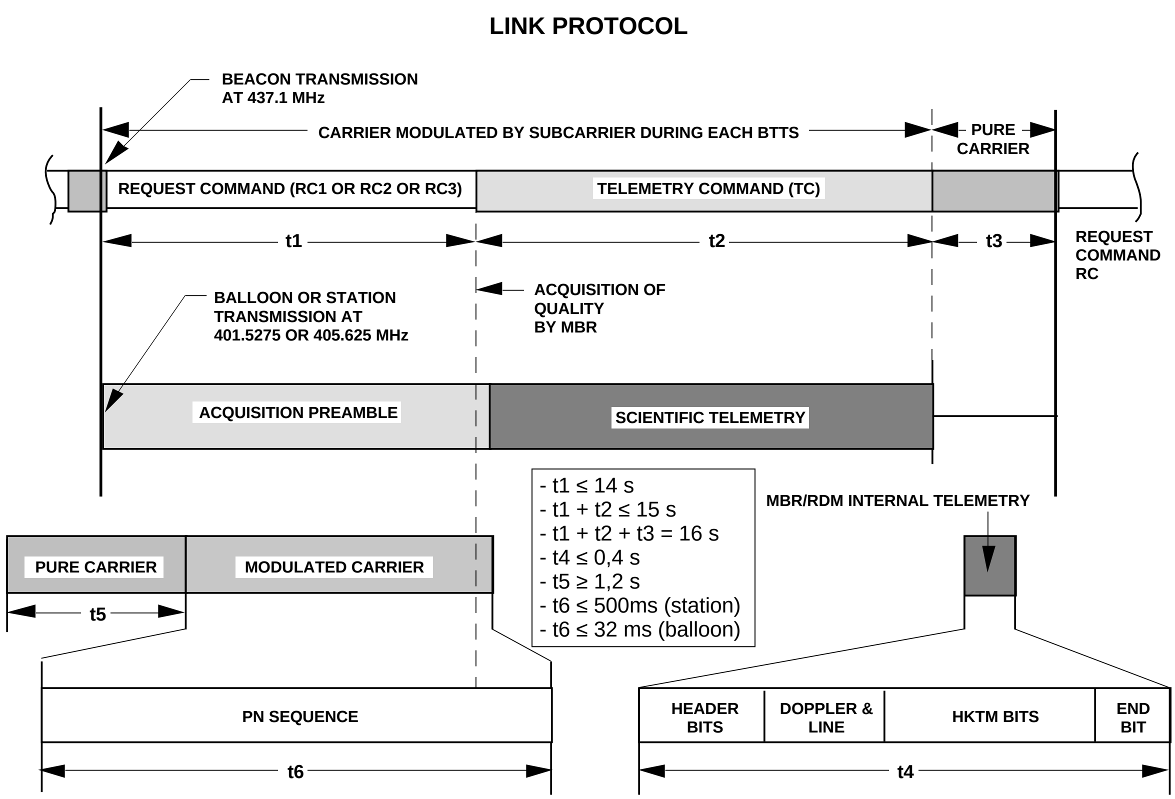


Figure E-2. Basic Transmission Protocol Exchange During a BTTS

The significant data bits obtained at the Viterbi decoder output will be transmitted to the MOC. The receiver signal processing unit will detect the end of the message. The data corresponding to the Doppler shift measurement obtained during the pass, the corresponding spacecraft time, and the MR housekeeping data bits will be sent after the scientific data bits and transmitted to the MOC.

E.4.5.2 MR to MOC. The data rate between the MR and the MOC typically will be 8 kb/s.

The electrical interface with the MOC consists of two lines:

(1) the data line at R1 (128038 b/s, or 129344 b/s for the gondola telemetry, or 128038/16 b/s for the small station and penetrator telemetry, or 16 kb/s for datation, Doppler measurements, and housekeeping telemetry).

(2) the data clock line with the corresponding frequencies.

The presence of the data lock at the input of the MOC will start the stored sequence of the MR message in the MOC memory.

E.4.5.3 Spacecraft to Earth. There shall be a ≥4-kilo symbol/second mode to support rapid transmission of MOC data at 2500 b/s during the relay period.

E.4.5.4 JPL-MOC. The link between the JPL and MOC facilities shall support a one-way transmission of a 32-megabit MOC file containing station data (4 stations x 2 passes x 4 Mb) within 1 hour of arrival at the JPL MGS PDB.

E.4.5.5 MOC to Users. A link between MOC and CNES shall support a two-way electronic transmission of surface station files. A similar link may exist between CNES, IKI, and the Babakin Center.

E.4.6 Command Requirements

There shall be 16 available commands, via four discrete lines from the spacecraft (see Table E-2). The nominal number of commands per day is TBD.

Table E-2. Proposed MR Commands

Mode Number	CMD3	CMD2	CMD1	CMD0	Lander	Beacon	Data Rate	RF Freq	Viterbi Decoder	Calling Order BTTS
M1	1	1	1	1	L1 only	ON	R1	F1	ON	RC1/TC
M2	1	1	1	0	L1 only	ON	R1	F1	OFF	RC1/TC
M3	1	1	0	1	L2 only	ON	R1	F1	ON	RC2/TC
M4	1	1	0	0	L2 only	ON	R1	F1	OFF	RC2/TC
M5	1	0	1	1	L1/L2	ON	R1	F1	ON	RC1/TC - RC2/TC
M6	1	0	1	0	L3 only	ON	R1	F1	ON	RC3/TC
M7	1	0	0	1	L3 only	ON	R1	F1	OFF	RC3/TC
M8	1	0	0	0	L3 only	ON	R2	F2	ON	RC3/TC
M9	0	1	1	1	L1/L2	ON	R1	F1	OFF	RC1/TC - RC2/TC
M10	0	1	1	0	L1/L3	ON	R1	F1/F2	ON	RC1/TC - RC3/TC
M11	0	1	0	1	L1/L3	ON	R1	F1/F2	OFF	RC1/TC - RC3/TC
M12	0	1	0	0	L1/L3	ON	R2	F1/F2	ON	RC1/TC - RC3/TC
M13	0	0	1	1	L3 only	ON	R1	F2	OFF	RC3/TC
M14	0	0	1	0	L1 only	ON	R2	F1	ON	RC1/TC
M15	0	0	0	1	Test 1	ON	R1	F1	ON	no modulation
M16	0	0	0	0	Test 2	OFF	R1	F1	OFF	NA

It shall be possible to initiate command requests at CNES, JPL, and MOC facilities. However, the actual command request to the spacecraft shall originate from a single source, to avoid conflicts. That single source must also be capable of issuing MOC commands when use of the MOC buffer is required. The command request will therefore be issued from the MOC facility. It is a goal that MR commands be radiated to the spacecraft within 24 hours following request input to the PDB for changes to the planned sequence.

E.5 MISSION OPERATIONS

E.5.1 Science Observations

Station operations shall commence in September 1997 (TBR). During the descent of each station (Figure E-3), an onboard framing camera (500 x 300 pixels) will acquire and store in the station's 32-Mbit memory up to 100 images. Because of the Mars '96 orbit geometry (Section E.8), these data may be relayed only to the MR during the first week of landed station operation.

Penetrator operation during this period is TBD.

Station data acquisition will be regularly uplinked to the MR, depending on pass duration (e.g., 1 Mb/sol/station or 200 to 300 kb/sol/instrument). The Mars '96 spacecraft will support data relay at rates varying from 1 Mb/sol/station to 1 Mb/week/station.

Data will be relayed at about 2 a.m. and 2 p.m. (Mars local time) by MR, and at about TBD by Mars '96.

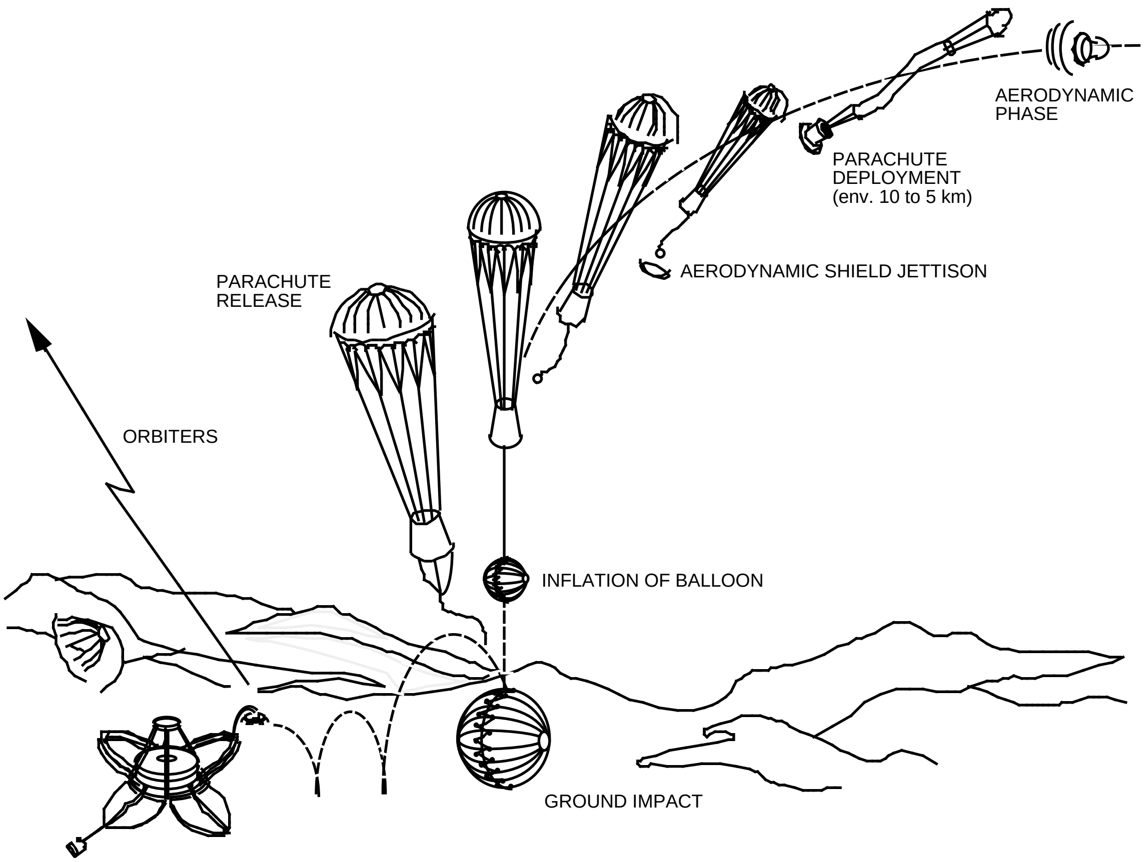


Figure E-3. Small Station Descent Scenario

E.5.2 Instrument Performance Evaluation

Capability will be provided for review of data acquired from individual instruments mounted on the stations to verify proper operation during the relay period. The instruments' performance will be monitored in near real time (with respect to Earth receipt).

MOC images may be acquired of the landing sites during the period of surface station operation. Predictions of the station locations will be provided by CNES to optimize use of the MOC buffer before expected acquisition. MOC data shall be available for retrieval by the MR monitoring and analysis team within 24 hours after Earth receipt. This may make possible correlation and interpretation of surface measurements (e.g., panoramic camera data).

E.5.3 Experiment Data Records

MR data are returned from the spacecraft embedded in MOC packets. The data will normally be stripped at MOC, where capabilities will ensure proper and timely processing. The data will be returned to the PDB.

The station image data, in general, will be compressed prior to transmission from the surface. The capability to decompress the data shall be available at the MOC facility. The availability of this capability at CNES is also important for evaluation of the quality of the data compression. The decompression will cause an increase in data volume of up to a factor of 10. The QQC of the data shall be >95% of ground-received telemetry, with a BER of $\leq 10^{-5}$ and a maximum gap duration of 10 s. (Note that the MR data are not compressed inside the MOC. They only use the MOC mass memory for storage.)

The total (compressed) data return for a single station will be about 200 Mb.

The MR data shall be available to the MOC ground facility within 24 hours after Earth receipt.

MR data shall be returned from the MOC ground facility to the PDB.

The MR data shall be available to CNES within 1 hour after they are extracted at the MOC facility.

Access to the PDB for MR users shall be available at the MOC facility.

Data base inputs may be either EDR (compressed) or RDR (meteorology products; images from descent and panoramic cameras; alpha, X-ray, or neutron spectrometer; magnetometer or seismometer records).

E.5.4 Planning Aids

Software to determine the location of the surface stations will be developed by CNES and delivered to the MOC facility.

The SPICE kernels and toolkit shall be available to MR users and CNES during operations. The SPICE system should provide knowledge of the location of the spacecraft within 2.5 km (goal) during surface station operation.

E.6 SCIENCE ANALYSIS

E.6.1 MOC Facility Support

The MOC facility shall be able to accommodate one or more Relay representatives during MR operations and, as a goal, throughout the duration of the MR activity.

E.6.2 Computer Facilities and Workstations

The workstations supporting the MR (including the SOPC) require the following capabilities:

- Prediction of MGS orbiter path (MGS Project)
- Prediction of Mars '96 visibility (CNES)
- Reconstruction of station location (MOC/CNES at MSSS)
- Access to PDB (MGS Project)
- Command generation (by MGS Project SCT)
- Telemetry depacketization (MGS Project/MOC)
- Decompression of MR/station data (CNES/MOC)

- Support of near-term analysis (CNES/MOC)
- Support of communication function with investigators (MGS Project)
- Graphic image display (MGS Project/MOC)

The workstations shall be located at the MOC ground facility.

The MR GSE will be located at CNES.

E.6.3 Reduced Data Record Archiving

Reduced records will be deposited in the PDB. Access to these records shall be consistent with Project policy.

E.6.4 Project Data Base

The data to be deposited in the PDB arises from two sources: descent observations and surface measurements.

E.6.4.1 Descent Observations. The data are stored in the station 32-Mb mass memory, consisting mainly of images from the descent camera and some magnetometer data. The compression ratio of 10:1 gives a total of 320 Mb to be returned to the PDB.

E.6.4.2 Surface Measurements. A maximum of 1 Mb/day x 150 (TBR) days yields 150 Mb of data return per station. These data are not compressed, except for a few images from the panoramic camera.

E.6.4.3 Data Archives. The total archived data set should not exceed 1 Gb per station.

E.6.5 Surface Station Measurements

The small surface stations provide a variety of measurements, notably meteorological measurements, alpha, X-ray scattering spectrometer, magnetometer, seismometer, and high-resolution photography of the surface.

E.6.5.1 Small Surface Stations. The nominal scientific payload of the small surface station consists of:

(1) Meteorology Instrument System (MIS), including temperature, pressure, humidity, wind, and optical depth sensors.

(2) Descent Phase Instrument (DPI), including acceleration, pressure, and temperature sensors.

(3) Alpha, X-ray, and neutron spectrometer.

(4) Magnetometer (Optimism experiment).

(5) Seismometer (Optimism experiment).

(6) Panoramic camera (PanCam).

(7) Descent phase camera (DesCam).

The operations are controlled by the Station Data Processing Unit (SDPU). The telecommunication unit consists of a transmitter and a receiver that detects the carrier signal of an orbiter. The power supply comprises an RTG and a rechargeable battery. Power electronics consists of charge and discharge electronics and dc/dc converter.

Before landing on Mars, the parachute and the station cover will be ejected (Figure E-3). Figures E-4 and E-5 illustrate the small surface station as seen before launch and following landing on Mars.

On the Martian surface the MIS, alpha spectrometer, magnetometer, seismometer, and PanCam will receive power from the station battery according to a pre-selected schedule. For most of the Martian ground operation time, the surface station will be in a standby state. It will wake up at regular intervals and decide whether there is something to be done. After completing its task or if there is nothing to be done, it returns to the standby state.

The station will make decisions on measurement starting time according to the time of day, transmission sequences, and other factors.

The measured data will be sent to Earth via the Mars Global Surveyor and Mars '96 orbiter. The data will be transmitted when the station receiver hears the Mars '96 orbiter or Mars Global Surveyor carrier. Also the descent phase data will be sent after landing on Mars. The small surface stations will form a Martian network consisting of two stations. In addition to the stations there will be penetrators to be deployed on the Martian surface.

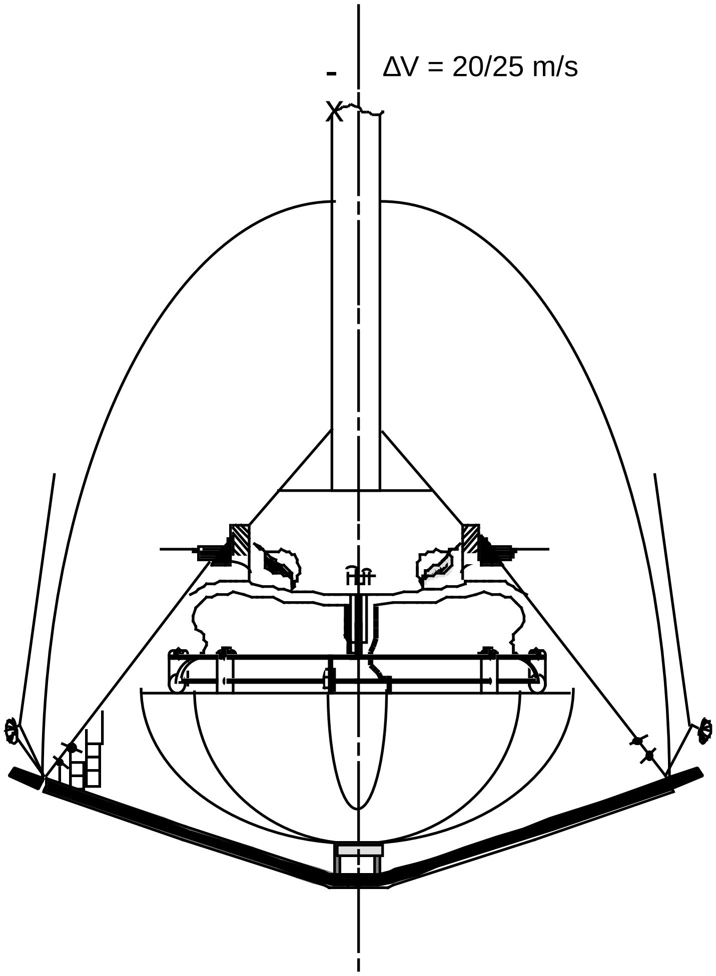


Figure E-4. Mars’96 Small Station (side view before launch)

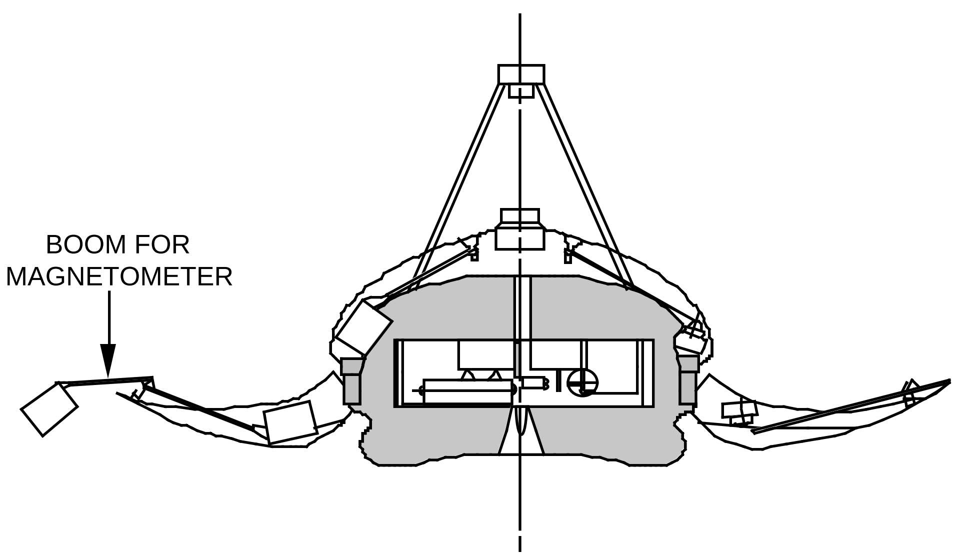


Figure E-5. Side View of Landed Small Station

The exact scientific measurement sequences are TBD. The following tasks comprise the station operations on Mars:

(1) Wake up at regular intervals (≈ 60 seconds) and decide what to do. Remain in a standby state during most of the operation time.

(2) Record some station activities in a logbook.

(3) Make meteorological measurements.

(4) Place instrument measurement data in the serial bus.

(5) Perform self-diagnostic checks.

(6) Listen to the receiver at regular intervals and transmit data to the orbiters.

The station will be awakened at regular intervals by hardware. All the other station actions will be activated by software commands. There exists a special order for each experiment and sensor, and also for the measurement time for each sensor. Available power is the most demanding parameter that will affect the control of all the station actions. The station will simply follow a deterministic operations program. By means of self-diagnostic data, the station can determine whether it needs to modify the default operations order and time allocated to each operation.

The power supply consists of two RTGs, a rechargeable battery, charge and discharge electronics, and a dc/dc converter. The following specifications are currently known:

RTG	Electrical power	200 mW
	Voltages	15 ... 30 V
Battery	Voltage	15 V nominal (13 V min, 16 V max)
	Max discharge	3 A
	Capacity	1 Ah
		<1000 cycles with 50% DOD (<20% DOD preferred)

The station will have three separate time information sources on board:

(1) Accurate relative time information from a real-time clock.

(2) Rough relative time from a simple standby oscillator and a counter located in the data memory.

(3) Rough time information with the aid of an optical sensor and meteorological sensors (local time information)

A real-time clock is needed to link together measurements of separate stations. Required timing accuracy for the optimism experiment is 1 s after processing of time data. For the other instruments the required timing accuracy is lower. The real-time clock is started when the station is separated from the spacecraft.

The resolution of the RTC is 0.01 s. The accuracy of the oscillator is dictated by the crystal. An AT-cut crystal has an accuracy of 50 ppm over a temperature range of –55˚ to +100˚C.

By optical and meteorological instrument measurements it is possible to determine noontime, sunrise, sunset, and day or night. This information will be used to control those station operations requiring connection to the local time.
The interconnections of the instruments of the surface station are shown in Figure E-6.

E.6.5.2 Penetrators. Although information on the penetrator payload has yet to be provided, Table E-3 and Figure E-7 present characteristics of its radio system.

Table E-3. Penetrator Radio System Characteristics

Transmitter frequency	401.5275 MHz
Receiver frequency	437.1 MHz
Antenna gain	–3 dBi
Transmitter power at antenna input	0 dBW
Modulation:	
Penetrator->MGS link modulation index	PSK, 60˚ ±6˚
MGS->Penetrator link frequency deviation	FSK, ±(4.3 ±0,2) kHz
Anti-noise coding	Convolution code: K = 7, R = 1/2
Data bit rates	2, 8, 16 kb/s
Receiver noise temperature	200 K
Local oscillator stability:	
1 s	$\pm 10^{-7}$
total mission	$\pm 10^{-5}$
Losses, antenna to receiver	0.6 dB
Required input power	–155 dBW
Mass	1.35 kg
Supply power	7.125 W

E.7 MARS '96 MISSION DESCRIPTION

The proposed Russian Mars '96 mission would consist of one orbiter spacecraft launched in November 1996. The orbiter would carry four surface science stations (two penetrators and two small stations) to be released on approach to the planet. The orbiter would arrive at Mars in early September 1997 and be inserted into an elliptical orbit around the planet. The landed packages would arrive and begin operating at the same time.

Figure E-8 shows a timeline for the Mars Global Surveyor activities.

The normal housekeeping measurements will be done at regular intervals. A complete self-diagnostic routine will be carried out at an interval of TBD. At least any short circuits that are under software-controllable power switches should be detected and eliminated.

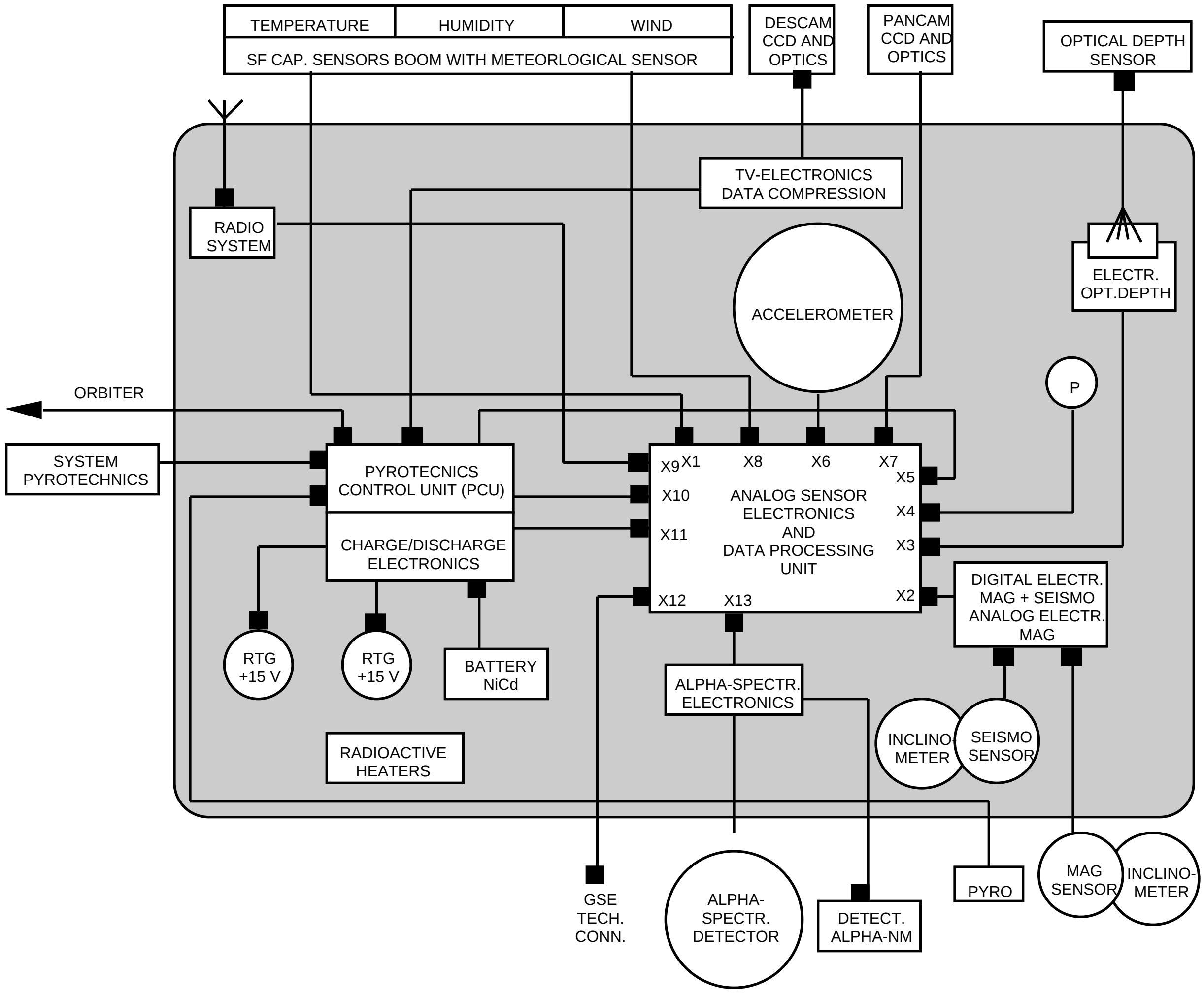


Figure E-6. Surface Station Data-Handling Interconnections

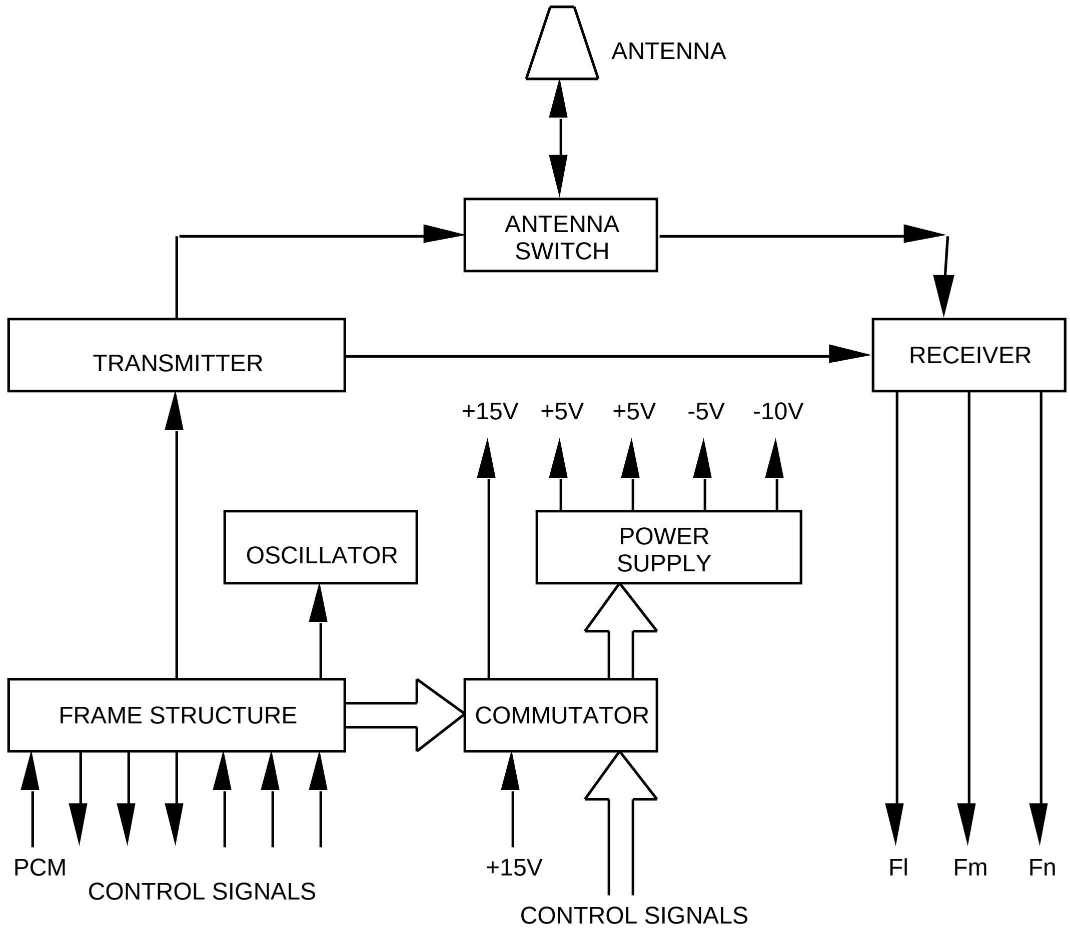


Figure E-7. Penetrator Radio System Structure

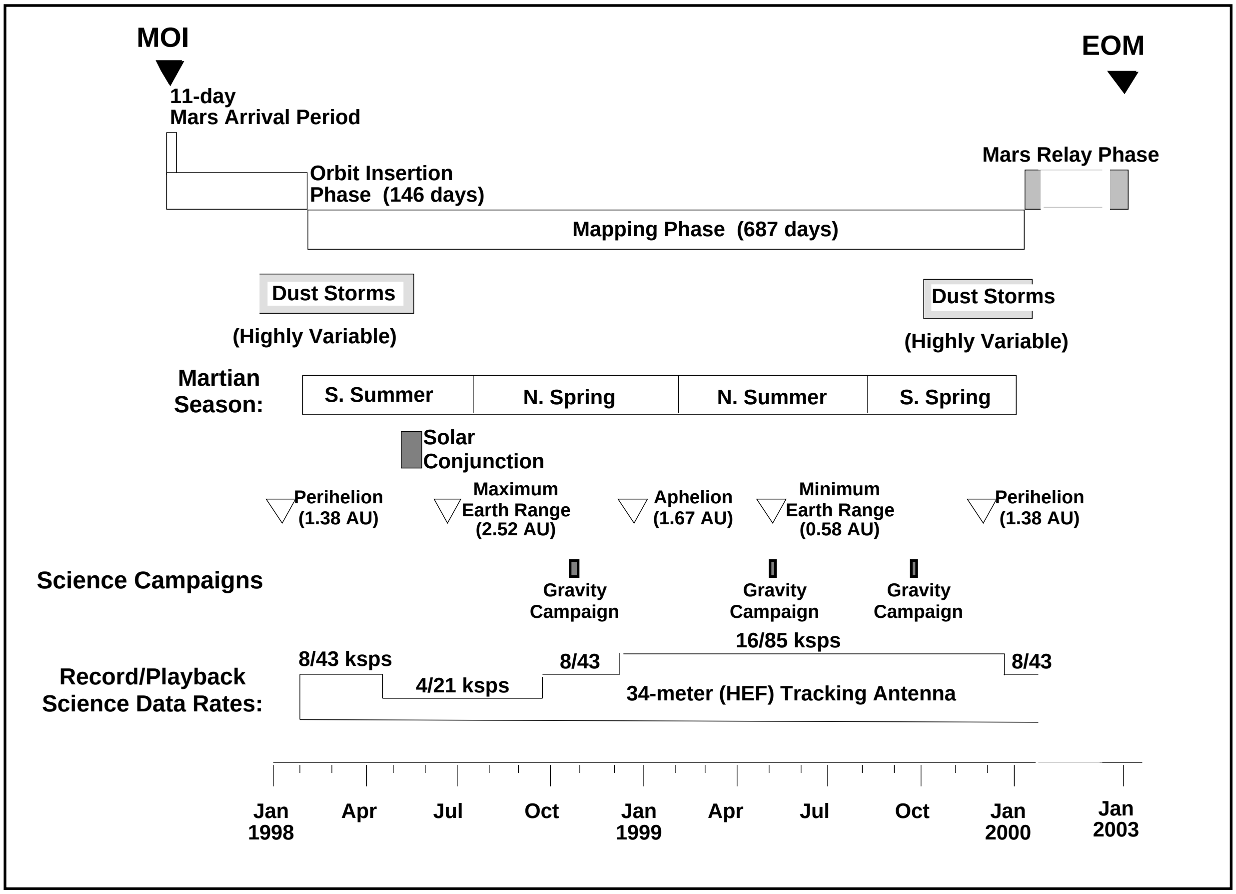


Figure E-8. Mars Global Surveyor Activity Timeline

Data will be stored on the surface stations, then sent up to either Mars Global Surveyor or the Mars '96 orbiter during brief contact periods each day, then subsequently relayed to Earth. Data transmissions to Mars Global Surveyor will be initiated by the MR downlink signal when the spacecraft passes close enough to the surface stations, typically for periods of no more than 10 minutes. There will be at least two of these contact periods per day, one in the afternoon at about 2 p.m. (local time) and the other at night, about 2 a.m.

E.7.1 Mars '96 Trajectory Description

The Mars '96 mission will utilize a type II interplanetary trajectory with a flight time of about TBD days. Launched by a Proton vehicle in November 1996, the orbiter will arrive at Mars in early September 1997 and be inserted initially into an elliptical orbit with a TBD period and a periapsis altitude of about TBD km. This orbit, designated as the capture orbit, will be inclined at 20˚ (TBR). After several maneuvers, the inclination will be adjusted to 88˚ (TBR), the period to TBD hours, and the periapsis altitude to 300 (TBR) km near the equator. The orbit, however, is not Sun synchronous, and the periapsis drifts northward and toward the terminator.

Because of the high orbital velocities near periapsis, the Mars '96 passes over surface stations near the equator are quite brief during the initial relay period and cannot be supported on the night side due to transmitter power limitations. As the periapsis moves northward, a similar situation becomes evident for the 40˚N station. Data relay with Mars '96 is planned at 8 kb/s. It is anticipated that the small surface stations will require relay support for at least one terrestrial year.

E.7.2 Mars Global Surveyor Data Relay Scenario

Figure E-8 shows the level of DSN tracking coverage and the recorded data rate that would be used by Mars Global Surveyor during the period of support to the Mars '96 mission. The MR experiment would be activated after about 10 September 1997, and the MOC would be configured for the storage and transfer of MR data. For about the first three weeks after the arrival of the Mars '96 orbiter, Mars Global Surveyor may provide the only data relay from the landed packages, from its post periapsis passage opportunities in the MGS aerobraking orbit. During this period the recorded data rate will be 8 kb/s, and the associated MOC data rate of 2856 b/s in the MRC data mode will easily accommodate the rather modest volume of data to be relayed from the stations.

During the period from post-aerobraking to the end of station life, relay support for the stations will augment the scientific data return from Mars '96 and provide supporting data from the Mars Global Surveyor payload during the period of expected dust storm disturbances as Mars approaches perihelion. During this period, as the Earth-to-Mars range increases, the recorded data rate can be only 4 kb/s. Spacecraft power should not be a constraint on operations of the MR in this period because Mars is approaching perihelion.

E.8 MARS '98 MISSION DESCRIPTION

The proposed Russian Mars '98 mission might consist of one orbiter spacecraft launched in November 1998. The orbiter would carry a descent module (600 kg) containing one balloon (lifetime ≈10 days) and one small rover (lifetime ≈1 terrestrial year) to be released from Mars orbit. The spacecraft would reach the vicinity of Mars at the beginning of TBD and release the balloon early in TBD, sufficiently ahead of the beginning of the dust storm season.

E.9 MARS SURVEYOR ‘98 MISSION SUPPORT

The proposed Mars Surveyor '98 mission consists of one lander and one orbiter. The lander is a free-flier with a cruise stage that ejects before entry. The lander telecom will consist of a UHF transceiver that can communicate with the MR for lander data transmission on the MGS or communicate bi-directionally with the UHF transceiver on the '98 orbiter, and a two-way direct-to-Earth X-band link that is used during cruise and while on Mars. On Mars, the direct-to-Earth link will provide commanding and a backup data return link to Earth if the UHF link was not available. The lander will arrive at Mars TBD [expect Aug-99 (Type 1 trajectory) to Jan-00 (Type 2 trajectory)] and will enter the atmosphere using a direct trajectory. Surface lifetime is TBD.